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OUR NEW AERIAL HIGHWAYS[1]

BY

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I deeply appreciate the opportunity to appear before this joint meeting of The Franklin Institute and the Philadelphia Section of the Institute of Aeronautical Sciences.

It is extremely important, in light of the international situation, that we stop for a moment to take inventory of our existing aids to air navigation and traffic control as well as those that are proposed for future use. I would like to take advantage of this meeting to outline just what has been accomplished in implementing the "Common System" of all weather navigation that will one day be the basis of a completely new system of "aerial highways."

As you all know, the term "Common System" describes the facilities that ultimately will provide air navigation and traffic control assistance to all segments of aviation in the United States, military, scheduled airlines, non-scheduled and executive as well as personal flying.

While the Civil Aeronautics Administration is responsible for the installation and operation of the equipment of the "Common System," the plan for the implementation of the facilities was developed in a report by Special Committee No. 31 of the Radio Technical Commission for Aeronautics.

The "Common System," when finally completed in the mid-1960's, will be the result of industry-government team-work of the highest degree. No one agency or segment of the industry could possibly

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embark on a project of this magnitude and successfully carry it through. This "Common System" has had, and will require in the future, the full support and complete cooperation of all the users of the airways.

Speaking of cooperation, I would like to digress for a moment to say a few words about The Franklin Institute's part in the RTCA program. This Institute is conducting an important measurement study under contract with the Air Navigation Development Board (ANDB). Just under way, this study will provide information that will be integrated with the information already available on the subject. This study, extending about a year, will explore the part the human element plays in the operation of aircraft. It has long been known that the human element is an important factor in aircraft operation but to date we have not precisely defined just what part it plays. The Franklin Institute will attempt to determine the differences in the operation of similar aircraft by different pilots. I understand that radar will play an important part in this study.

The complete report should be most interesting and I am sure will prove of tremendous value to the ANDB in its work of recommending the devices and equipment that will comprise the airways navigation aids of the future.

Back now to our discussion of the "Common System." I think it would be appropriate at this time to give you some idea as to the method and procedures your Government is following in order to reach the goals set forth in the SC–31 Report.

The Air Navigation and Traffic Control Panel of the Air Coordinating Committee was established about two years ago and is charged with the responsibility of developing the operational requirements for aids to air navigation and traffic control and transmitting these requirements to the ANDB.

The Panel consists of Government agencies and representatives of the aviation industry and private citizens responsible for the implementation of the "Common System" or concerned with the use of the Federal Airways.

The ANDB, upon receipt of the operational requirements for the aids to air navigation, formulates a program for research on, and the development of, aids for both the transition and ultimate "Common System." The ANDB is housed in the Department of Commerce and has representation from the Army, Navy, Air Force and Civil Aeronautics Administration with a chairman from private industry.

After development of an air navigation aid, specifications are drawn up and presented to the implementing agencies. It is the responsibility of the CAA to plan for, procure, install and operate the ground aids required for the "Common System" throughout the United States and its territories and possessions.

The report of Special Committee No. 31 is premised on an ultimate

program of air navigation and traffic control aids that we hope will be available to all users of the airspace by the middle 1960's and a transition program that should be completed by the end of 1953.

The transition program involves many different types of navigation aids. The equipment involved in the transition program may be classified into three categories:

1. Equipment which at the time the SC–31 Report was written was already out of the development stage and available for procurement. Under this heading we find the Instrument Landing System, the Very High Frequency Omnirange and the Very High Frequency Communications.

2. Equipment which, although under development, was sufficiently advanced to permit a relatively accurate forecast of performance and availability. Under this grouping we find Distance Measuring Equipment (DME), Very High Frequency Automatic Direction Finders (VHF/ADF), Airport Surveillance Radar, Precision Approach Radar and High Intensity Approach Lights.

3. That equipment either in the very early stages of development or on which development had not yet been started, but which, nevertheless, did not appear to offer problems that would preclude its use during the transition program. In this category we find the Private Line Communications, Airport Time Utilization Equipment, Airport Surface Detection Equipment, Secondary Radar and Mechanical Interlock.

The implementation of Group 1 is very nearly completed. It is worth noting at this time that the CAA put into operation within the past month the Nation's first controlled airway based on the new omnirange. This new airway extends through six states in the midwest and Southwest and links such important air terminals as Kansas City, Denver, Albuquerque, Omaha, Wichita, Oklahoma City, El Paso and Fort Worth. The new route is approximately 4380 miles long and operates on signals from 41 omnirange stations.

Implementation of Group 2 is still in the early stages although procurement of some equipment is well underway.

In Group 3, the Mechanical Interlock has emerged from the development stage and delivery of the equipment is well along. The implementation of the remaining items in Group 3 is, however, still well in the future and depends largely on the rate at which development can be completed.

Some idea of the magnitude of the "Common System" may be gained by considering the estimates contained in the original SC–31 Report. The combined transition and ultimate programs as estimated in the SC–31 Report would involve the expenditure of $1,111,800,000, of which $376,900,000 would be required for airborne equipment. It goes without saying that a program of this size and importance required

broad and detailed planning, the development of criteria, the mobilization of the Nation's operational and technical know-how and the full support of the Congress and the tax-paying public. It should be kept in mind in considering both the transition and the ultimate programs that the recommendations contained in the SC–31 Report must necessarily be considered as guides rather than directives. A program such as this must be under continual study and re-evaluation on the basis of technological developments in aircraft, operational changes, economic conditions and even international conditions. For these reasons, it is quite conceivable, even probable, that the numbers of facilities as specified in the transition program by the SC–31 Report, should undergo some changes. For example, the present Instrument Landing System Program covers the majority of the large air terminals of the country, yet the present implementation covers less than 50 per cent of that scheduled by the SC–31 Report. Costing something a little over $100,000 per unit, it will be appropriate to inquire into the justification of additional ILS installations. This does not necessarily mean that no further ILS installations will be approved, nevertheless we can assume at this stage that at certain airports having low air traffic density, it would be true from the standpoint of the implementation agency as well as from the standpoint of the taxpayers who have to bear the costs.

1. The Instrument Landing System Program
   (*a*) 350 proposed by SC–31 Report.
   (*b*) 92 commissioned as of September 1, 1950.
   (*c*) 171 authorized through current fiscal year.
2. High Intensity Approach Light Program
   (*a*) 350 proposed by SC–31 Report.
   (*b*) 5 commissioned as of September 1, 1950.
   (*c*) 33 authorized through current fiscal year.
3. Distance Measuring Equipment Program
   (*a*) 816 proposed by SC–31 Report.
   (*b*) Facilities presently operated for test purposes only.
   (*c*) 439 authorized through current fiscal year.
4. Precision Approach Radar Program
   (*a*) 96 proposed by SC–31 Report.
   (*b*) 4 commissioned as of September 1, 1950.
   (*c*) 28 authorized through current fiscal year.
5. Airport Surveillance Radar Program
   (*a*) 172 proposed by SC–31 Report.
   (*b*) 4 commissioned as of September 1, 1950.
   (*c*) 56 authorized through current fiscal year.
6. VHF/ADF Equipment Program
   (*a*) 228 proposed by SC–31 Report.

(*b*) None commissioned to date.
(*c*) 62 authorized through current fiscal year.

7. Omnirange Program
   (*a*) 466 proposed by SC–31 Report.
   (*b*) 294 operating, of which 271 commissioned as of September 1, 1950. In addition, there are 64 commissioned VAR ranges which will ultimately be converted to omni operation.
   (*c*) 415 authorized through current fiscal year.
8. Mechanical Interlock Program
   (*a*) 50 proposed by SC–31 Report.
   (*b*) 5 commissioned as of September 1, 1950.
   (*c*) 48 authorized through current fiscal year.

In addition to the projects listed, planning and development projects are under way for use of Secondary Radar, Airport Surface Detection Equipment, Air Traffic Control Signal System and Airport Time Utilization.

Through Fiscal Year 1951 the Congress has appropriated $72,724,078 for the implementation of the Common System Transition Program. Large though this sum may seem, it is only approximately 28 per cent of the amount set forth in the SC–31 Report.

No review of the Transition Program would be complete without a discussion of those facilities which antedate the SC–31 Program and which are still in active use. The planned obsolescence of these facilities is a most important and practical problem from both the operational and economic standpoints. As of this date, however, the CAA has not discontinued any of these obsolete aids as a result of the implementation and commissioning of new facilities. The discontinuance of these facilities will be governed by the speed of the implementation of the airborne installations required to fit the new facilities. We are therefore in the position from the operational and economic viewpoint of having simultaneous operation of both the older and the newer aids.

The present plan calls for a start in the discontinuance of low-medium frequency ranges, beginning in 1952. However, homing and beacon facilities will be required for some time where no other aids are available.

A comparison of the progress made against that recommended in the SC–31 Report would show that we are running close to schedule. There are, however, two determining factors in keeping abreast of the schedule, the first being the availability of funds and the second, and this is most important, is the rate at which the various users of the airways are able to equip their aircraft with the airborne devices necessary for the effective utilization of the new airways. As long as a sizeable number of aircraft are dependent on the low-medium frequency system, it will be impossible to realize the full benefits to be derived

from the new very high and ultra high frequency system that is gradually being made available.

The installation of airborne equipment is just as important to the "Common System" as the installation of the ground equipment. The Air Transport Association and Aeronautical Radio Incorporated, are working with the various radio manufacturing companies and the Government in perfecting economical airborne equipment. Relatively inexpensive and light-weight omni equipment for personal type aircraft which were patterned after models developed through CAA research are now available.

There is no doubt that the "Common System" will some day provide to the aviation industry the same benefits that our great system of highways has provided for the automotive industry. As a matter of fact, results from the equipment already installed are gradually becoming apparent. The record shows that 87,659 instrument approaches were made in 1944. These instrument approaches represented a total of roughly 4630 hours of delay in the air in the terminal areas of the airports involved. The average delay for each approach back in 1944 was 3 minutes and 10 seconds. The latest statistics for 1949 reveal there were some 293,939 instrument approaches, or over three times as many. True, the total delay time increased to 5946 but the average delay time for each approach was cut back from 3 minutes and 10 seconds to one minute and 13 seconds. These are extremely significant figures and illustrate the advances made in the efficiency of our air traffic control system.

As encouraging as our advances have been, we are only beginning. Every segment of the aviation industry must work and plan for the future of aviation in this country. I firmly believe the "Common System" is the answer to our all weather flying problems. Once we have hurdled that big obstacle we can, I am confident, solve the other problems as they arise.

SIMPLIFIED INTERFLECTION CALCULATIONS

BY

PARRY MOON [1] AND DOMINA EBERLE SPENCER [2]

1. INTRODUCTION

The predetermination of the distribution of light in rooms is of fundamental importance in lighting and enters into the design of every outstanding lighting installation. Thanks to the integral equation for interflections, it is now possible to calculate the average pharosage at table level, also the helios of walls, floor and ceiling (1).[3] The equations (2), however, are very complicated and require too much computational labor for ordinary engineering use. Accordingly, tables (1, 2, 3) were computed by means of the fundamental equations, and these tables are finding considerable application in illuminating engineering.

The outstanding peculiarity of the subject is the large number of independent variables. Even with a given type of lighting and a given luminaire, there are four independent variables—the room shape (specified by the *domance* k_r), and three reflectances (of walls, floor, and ceiling). This characteristic of the problem made graphical presentation difficult and led to the use of tables (3). The tables have certain disadvantages, however, since they may require interpolation or extrapolation with respect to four variables. It seemed advisable, therefore, to see what other methods of presentation could be devised.

The present paper gives the results of this investigation. In the first place, we find that the previous equations can be approximated over the usual range of the variables by very simple exponential relations. In this way, the four independent variables are handled easily by use of an ordinary slide rule, and the calculated values are generally good enough for engineering practice. Nomographic charts are presented as an alternative method of calculation. Also, if we confine ourselves to one type of lighting and to standardized reflectances, we can plot standard curves that give an easy visualization of the problem. Finally, special slide rules can be devised. These four methods of presentation will be considered in order: (*a*) approximate formulas, (*b*) alignment charts, (*c*) standard curves, and (*d*) slide rules. The paper will be confined to ceiling lighting (Type II) but the same methods can be applied to other methods of lighting.

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[3] The boldface numbers in parentheses refer to the references appended to this paper.

2. APPROXIMATE FORMULAS

It was hoped at first that some kind of "equivalent reflectance" could be found, such that the three independent reflectances could be replaced by a single variable, as was done in replacing the three independent room dimensions by a single quantity (3), the *domance* k_r. The reflectances enter the equations in such a complicated way, however, that no such step seems possible.

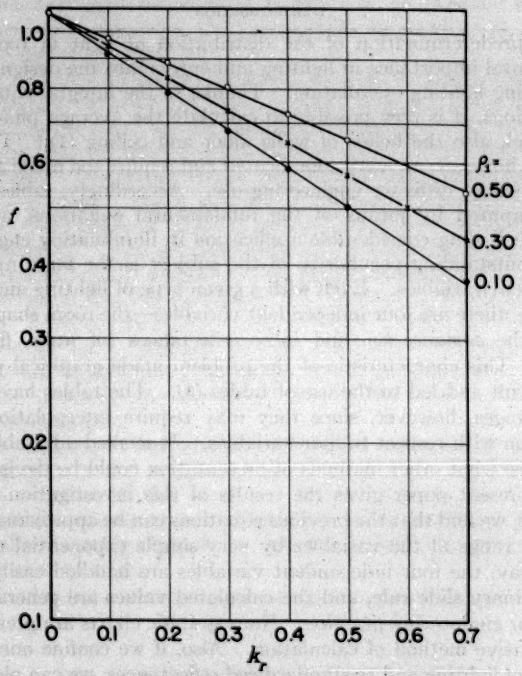

FIG. 1. Interflectance curves for ceiling lighting (IIa).
$\rho_2 = 0.70$, $\rho_3 = 0.10$
Points represent tabulated values, straight lines represent exponential approximations.

Nor is there any apparent way of obtaining an analytic approximation of the original equations (2). When the results are plotted, however, they are found to be very close approximations to exponential functions of k_r. One set of curves is shown in Fig. 1. Similar results are obtained for helios of walls, ceiling, and floor. Since domance ordinarily ranges from approximately 0.1 to 0.7, the exponential curves of

Fig. 1 are seen to be excellent approximations over the usual range. For the rather unusual case of a cubical room ($k_r = 1$) or a room higher than its length ($k_r > 1$), the approximate formulas should be used with caution.

Symbols employed in this paper are the same as in the previous works (1, 2, 3). They are as follows:

ρ_1 = average reflectance of walls,
ρ_2 = average reflectance of ceiling,
ρ_3 = average reflectance of floor,
H_{1M} = helios (blondel) of walls midway between floor and ceiling,
H_2 = average helios (blondel) of ceiling,
H_3 = average helios (blondel) of floor,
S = area (m^2) of floor,
S_1 = total area (m^2) of walls,
$k_r = \dfrac{S_1}{4S}$ = domance of room,
F_L = total pharos (lumen) from lamps,
F_D = total pharos (lumen) from luminaires,
F_W = total pharos (lumen) incident on principal surface (3),
$f = F_W/F_D$ = interflectance of the room,
$g = F_D/F_L$ = logance of the luminaires,
$k_u = fg$ = coefficient of utilization,
$D_{AV} = fg\dfrac{F_L}{S}$ = average incident pharosage (lumen m^{-2}) on principal surface.

From Fig. 1 and similar graphs of the tabulated values (1), we can write

$$f = Ae^{-\alpha k_r}, \tag{1}$$

where A and α are functions of the reflectances but not of the domance. Evidently, A is the value for an infinite room ($k_r = 0$), and these values are known exactly from interflection theory (3). For interflectance,

$$A = \frac{1}{1 - \rho_2\rho_3}.$$

The values of α are determined by measuring the slopes of the curves (Fig. 1). A satisfactory empirical expression is found to be

$$\alpha = 1.530 + 1.20\rho_3 - 0.972\rho_1 - 0.820(\rho_1)^3. \tag{2}$$

Thus the fundamentally important quantity f is expressed approximately as

$$f = \frac{1}{1 - \rho_3\rho_2}e^{-\alpha k_r} \tag{3}$$

TABLE I.—*Comparison of Approximate Formulas with Previous Tables (Type IIa lighting with $k_r = 0.70$).*

Reflectances			f			H_{1M}/D_{AV}			H_2/D_{AV}			H_3/D_{AV}		
ρ_2	ρ_2	ρ_1	Table	Eq.	% Error	Table	Eq.	% Error	Table	Eq.	% Error	Table	Eq.	% Error
0.10	0.80	0.80	0.787	0.851	+8.1	0.594	0.597	+0.5	1.686	1.702	+1.0	0.0827	0.0830	+0.4
	0.70	0.50	0.534	0.549	+2.8	0.368	0.363	−1.3	2.113	2.120	+0.3	0.0777	0.0774	−0.4
		0.30	0.444	0.438	−1.4	0.220	0.215	−2.1	2.406	2.450	+1.8	0.0747	0.0739	−1.1
		0.10	0.378	0.365	−3.4	0.0728	0.0705	−3.2	2.705	2.832	+4.8	0.0718	0.0706	−1.7
0.30	0.80	0.80	0.863	0.872	+1.0	0.631	0.632	+0.2	1.625	1.665	+2.5	0.254	0.253	−0.4
	0.70	0.50	0.555	0.547	−1.4	0.388	0.385	−0.8	2.078	2.071	−0.3	0.236	0.237	+0.4
		0.30	0.454	0.436	−4.0	0.231	0.227	−1.7	2.386	2.396	+0.4	0.226	0.226	0
		0.10	0.383	0.363	−5.2	0.0765	0.0747	−2.4	2.699	2.773	+3.0	0.216	0.215	−0.5
0.10	0.50	0.50	0.515	0.538	+4.5	0.368	0.364	−1.0	2.113	2.120	+0.3	0.0777	0.0774	−0.4
		0.10	0.376	0.358	−4.5	0.0728	0.0705	−3.1	2.705	2.832	+4.8	0.0718	0.0706	−1.7
0.30	0.50	0.50	0.532	0.507	−4.7	0.388	0.385	−0.9	2.078	2.071	−0.3	0.236	0.237	+0.4
		0.10	0.380	0.337	−11.3	0.0762	0.0747	−2.0	2.691	2.773	+3.0	0.215	0.215	0

with α determined from Eq. 2. Similarly, the helios of the walls is approximated by the equation,

$$H_{1M}/D_{AV} = \frac{\rho_1}{2}(1 + \rho_2)e^{B_1 k_r}, \tag{4}$$

where

$$B_1 = 0.418 + 0.116\rho_1 - 0.772\rho_2. \tag{5}$$

The helios of the ceiling is obtained from the relation,

$$H_2/D_{AV} = e^{B_2 k_r}, \tag{6}$$

where

$$B_2 = 1.608 - 1.040\rho_1 - 0.160\rho_2. \tag{7}$$

For the floor,

$$H_3/D_{AV} = \rho_2 e^{-B_3 k_r} \tag{8}$$

with

$$B_3 = 0.544 - 0.330\rho_1 - 0.130\rho_2. \tag{9}$$

These simple equations allow the calculation of the usual quantities, f, H_{1M}/D_{AV}, H_2/D_{AV}, and H_3/D_{AV}, for any values of the reflectances. As stated previously, the equations are exact for $k_r = 0$ but generally exhibit an error that becomes progressively greater as k_r exceeds 0.7. For values of k_r beyond 1.0, the previous equations or tables (3) should be employed rather than the foregoing approximations. A comparison between tables and approximate formulas is given in Table I. In most cases, the error caused by using the new equations is not over 5 per cent.

3. ALIGNMENT CHARTS

Another way of handling problems that contain a large number of independent variables is to employ alignment charts or nomographic charts. Equations 2 to 9 were used in making the charts presented in Figs. 2 to 5. The charts contain the same approximations as the equations, but they are convenient if a large amount of numerical work is being done.

The simplest of the charts is Fig. 4. It consists merely of a vertical scale for ρ_1, a vertical scale for H_2/D_{AV}, and a grid with vertical lines representing constant values of k_r and slanting lines representing constant values of ρ_2. A straight edge, laid across the chart between the proper points on scale ① and grid ②, will intersect ③ at a point representing the value of H_2/D_{AV}.

The other alignment charts have the same basic arrangement of two vertical lines and a slanting grid. In addition, they contain two other scales which allow a final multiplication. In Fig. 5, line ③ has no scale. A point, located on ③ by the first operation, is connected to ④, and the value of H_3/D_{AV} is read directly from scale ⑤.

Figures 2 and 3 may be used in two ways: scale ③ may be read and the final result obtained from ③ by slide-rule computation, or the point

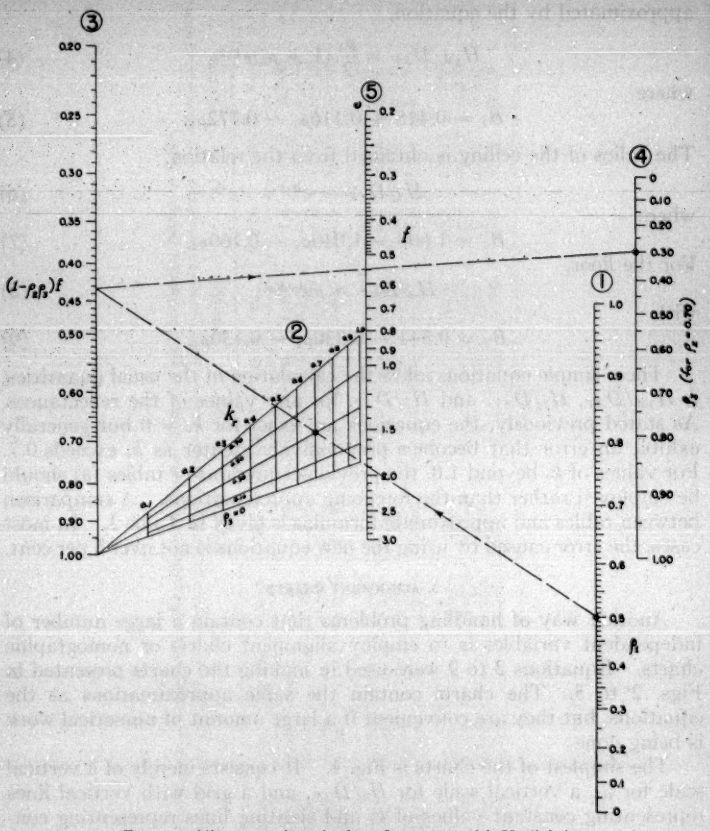

FIG. 2. Alignment chart for interflectance f with IIa lighting.

Scale ① is for wall reflectance ρ_1. Grid ② has vertical lines representing constant domance k_r, and slanting lines representing constant floor reflectance ρ_3. Select the proper points on ① and ② and connect them with a straight line. An extension of this line will cut scale ③, giving a value of the quantity $(1 - \rho_2\rho_3)f$. The interflectance f is then obtained by dividing this scale value by $(1 - \rho_2\rho_3)$.

For the special case of ceiling reflectance $\rho_2 = 0.70$, the division is eliminated by using scales ① and ④. Connect the point previously found on ③ with the point on ① representing the floor reflectance ρ_3. The value of f is then read directly from scale ⑤.

Example: Wall reflectance $\rho_1 = 0.50$, floor reflectance $\rho_3 = 0.30$, domance $k_r = 0.70$. Connect points on ① and ③ as shown by the dashed line. The value of $(1 - \rho_2\rho_3)f$ may be read from scale ③ and is found to be 0.433. This value applies to any ceiling. If the ceiling reflectance is 0.70, the value need not be read from ③, but the point is connected with $\rho_3 = 0.30$ on scale ①, giving a value of $f = 0.55$ on scale ⑤.

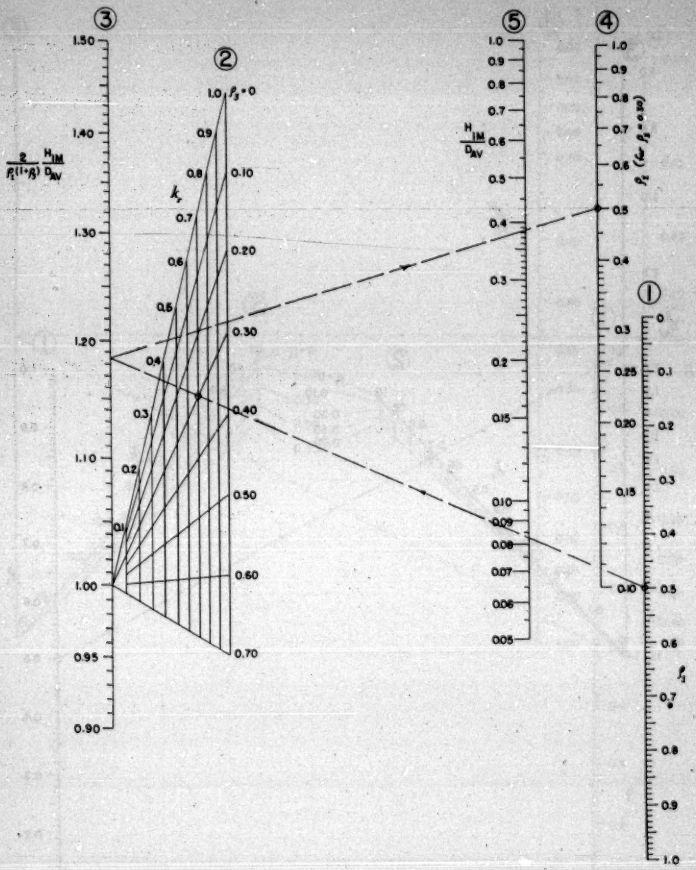

FIG. 3. Alignment chart for wall helios with ceiling lighting (IIa or IIb).

Connect the point on scale ①, representing the wall reflectance, with the point in the grid ③, representing the proper floor reflectance ρ_3 and domance k_r. The resulting value of

$$\frac{2}{\rho_1(1+\rho_3)}\frac{H_{1M}}{D_{AV}}$$

is read from scale ②. The wall helios H_{1M} is then obtained by multiplying the scale value by $\frac{\rho_1}{2}(1+\rho_3)D_{AV}$.

For the particular case of $\rho_3 = 0.30$, use scales ④ and ⑤. The previously determined point on ② is connected to a point on scale ④, and the intersection of this line with ⑤ gives H_{1M}/D_{AV}.

Example: Wall reflectance $\rho_1 = 0.50$, floor reflectance $\rho_3 = 0.30$, domance $k_r = 0.70$. Points on ① and ④ are connected by the dashed line, and the value on scale ② is found to be 1.185. If $\rho_3 = 0.30$, H_{1M}/D_{AV} is read (0.384) on scale ⑤.

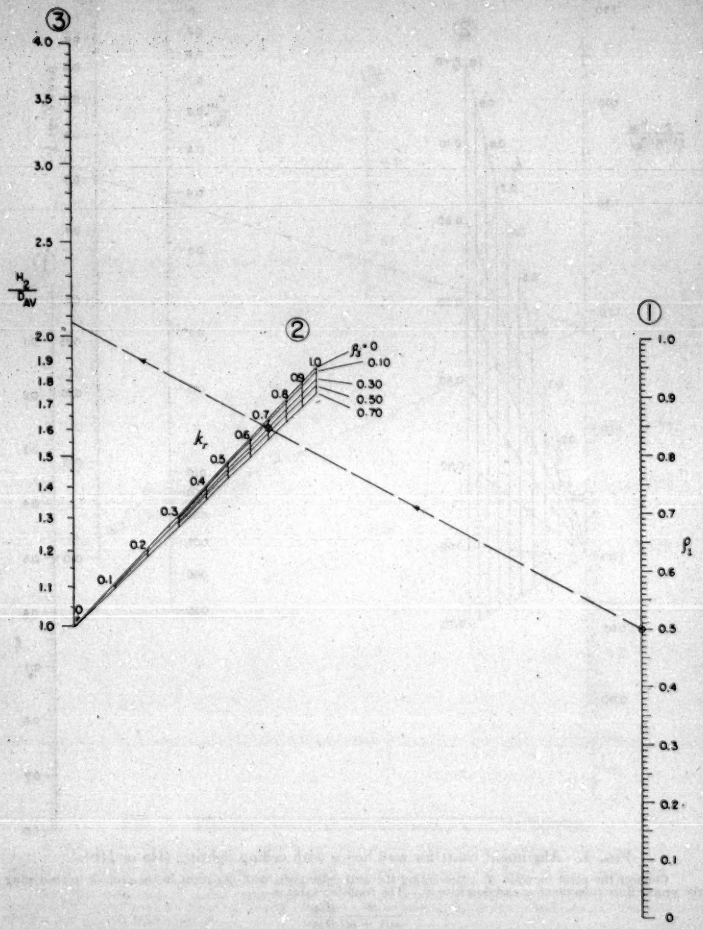

FIG. 4. Alignment chart for ceiling helios, ceiling lighting (IIa or IIb).

Connect the point on scale ①, representing wall reflectance, with the proper point in grid ③. The line will intersect scale ② at a point that represents H_2/D_{AV}.

Example: Wall reflectance $\rho_1 = 0.50$, floor reflectance $\rho_2 = 0.30$, domance $k_r = 0.70$. The points on ① and ③ are connected by the dashed line, giving $H_2/D_{AV} = 2.07$ on scale ②.

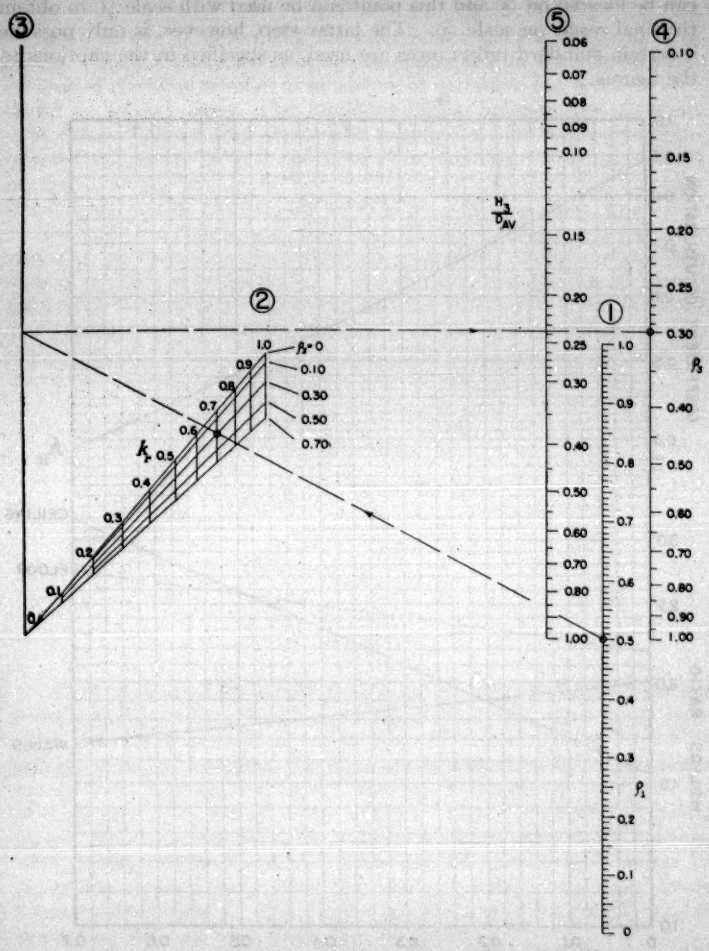

FIG. 5. Alignment chart for floor helios, ceiling lighting (IIa or IIb).

Connect the point on scale ①, representing wall reflectance, with the proper point in grid ③. The resulting straight line locates a point on ②. Connect this point with the floor-reflectance point on ④. The value of H_3/D_{AV} is read from scale ⑤.

Example: Wall reflectance $\rho_1 = 0.50$, floor reflectance $\rho_2 = 0.30$, domance $k_r = 0.70$. Points on ① and ③ are connected by the dashed line. The point of intersection with ② is then connected with $\rho_3 = 0.30$ on scale ④. This line intersects scale ⑤ at $H_3/D_{AV} = 0.238$.

can be located on ③ and this point can be used with scale ④ to obtain the final result on scale ⑤. The latter step, however, is only possible if certain standard reflectances are used, as specified in the captions to the figures.

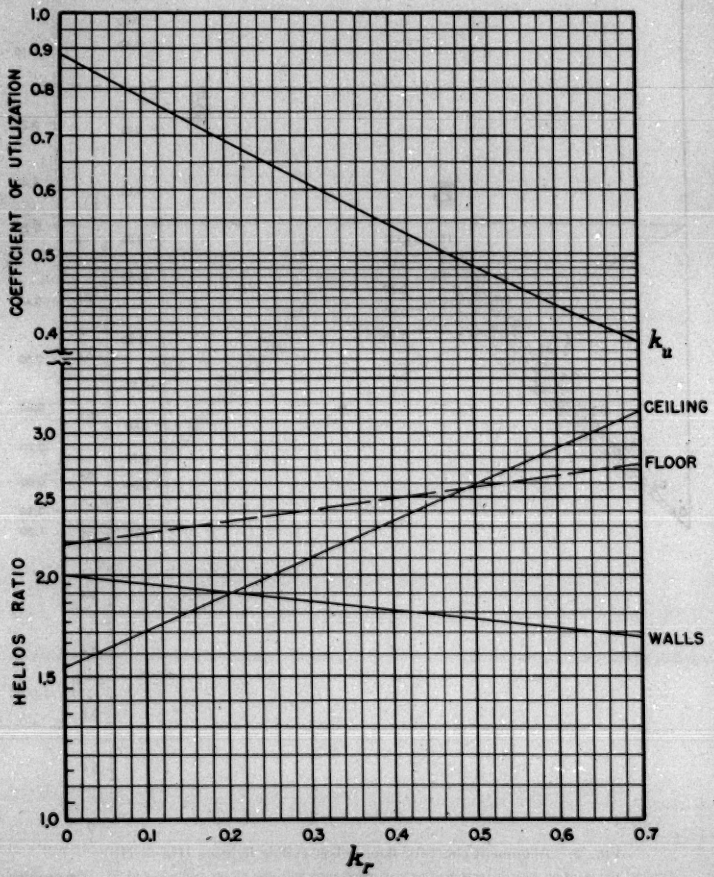

FIG. 6. Data for luminous-ceiling lighting (Type IIa).

The upper curve gives the coefficient of utilization k_u, which is employed in the equation,

$$D_{AV} = k_u \frac{F_L}{S}.$$

The other curves give helios ratios, H_3/H_A, H_A/H_1, and H_A/H_2. Values are taken from the tables (J. F. I., 242, 1946, p. 245) and are for $\rho_3 = 0.70$, $\rho_2 = 0.30$, $\rho_1 = 0.50$, $g = 0.70$, $\rho_A = 0.65$.

4. GRAPHS

Another way of presenting the interflection data is in the form of curves. Such a formulation is hardly practicable in the general case, because of the large number of independent variables, but becomes very useful in special cases. For luminous-ceiling lighting, the apparent reflectance of the ceiling (4) can be standardized at 0.70. If recommended values (5) of wall and floor reflections ($\rho_1 = 0.50$, $\rho_2 = 0.30$) are used, a single curve gives the interflectance f as a function of domance k_r. Curves can be plotted also for H_{1M}/D_{AV}, H_2/D_{AV}, and H_3/D_{AV}.

To make the curves more directly applicable to lighting design, one may plot the coefficient of utilization k_u instead of f and the helios ratios instead of ratios of helios to D_{AV}. But this step requires two additional data—the logance of the luminaire and the reflectance ρ_A of the work. For IIa lighting (4), the logance can be made 0.70 by careful design, while the adaptation reflectance for printed reading matter may be taken (3) as 0.65. Then

$$k_u = fg = 0.70f,$$

$$H_A = 0.65D_{AV},$$

$$H_2/H_A = \frac{1}{0.65}\left(\frac{H_2}{D_{AV}}\right),$$

$$H_A/H_1 = \frac{0.65}{(H_{1M}/D_{AV})},$$

$$H_A/H_3 = \frac{0.65}{(H_3/D_{AV})}$$

Figure 6 shows a set of curves obtained by use of these relations and based on the previously published tables (1). The upper curve indicates that the coefficient of utilization varies from almost 0.9 for an infinite room to less than 0.4 for a room with $k_r = 0.7$. The lower curves show that the desired 3:1 helios ratio is satisfied (3) over most of this range of k_r, though, with a cubical room, both floor and ceiling exceed the recommended ratio. Figure 6 applies only to IIa lighting, with parameters as specified. Other special cases can of course be plotted as needed, using either the tabulated data or the approximate formulas of Section 2. The graphs provide a very convenient way of presenting the data for a given type of lighting.

5. A SLIDE RULE

Slide rules can also be devised to simplify the interflection problem. Figure 7 shows a set of scales that were developed directly from Fig. 6. A logarithmic scale of k_u is employed, and the other fixed scales are graduated to fit this k_u scale in accordance with the curves of Fig. 6.

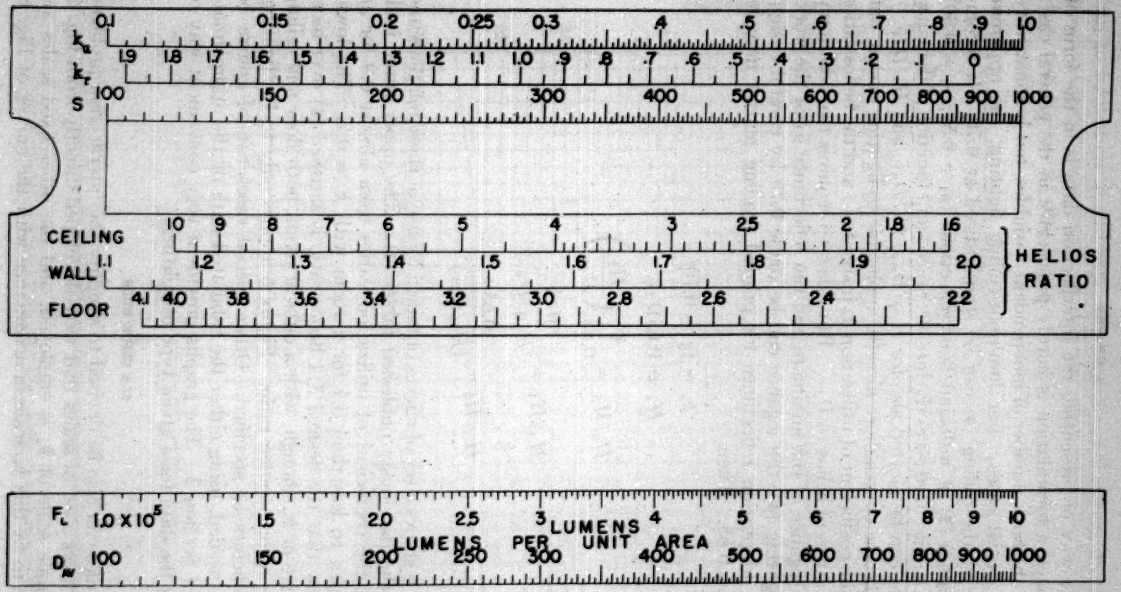

FIG. 7. Scales for a slide rule. Ceiling lighting (IIa), $\rho_1 = 0.50$, $\rho_2 = 0.70$, $\rho_3 = 0.30$, $g = 0.70$, $\rho_A = 0.65$ (applies also to IIb lighting with $\rho_1 = 0.50$, $\rho_2 = 0.80$, $\rho_3 = 0.30$, $g = 0.84$, $\rho_A = 0.65$).

The body of the rule, shown above, has scales for S (floor area), k_r (domance of room, $k_r = S_1/4S$), k_u (coefficient of utilization), and helios ratios. The slide, shown below the rule, contains scales of F_L (total lumens from the lamps) and D_{AV} (average lumens per unit area on principal surface).

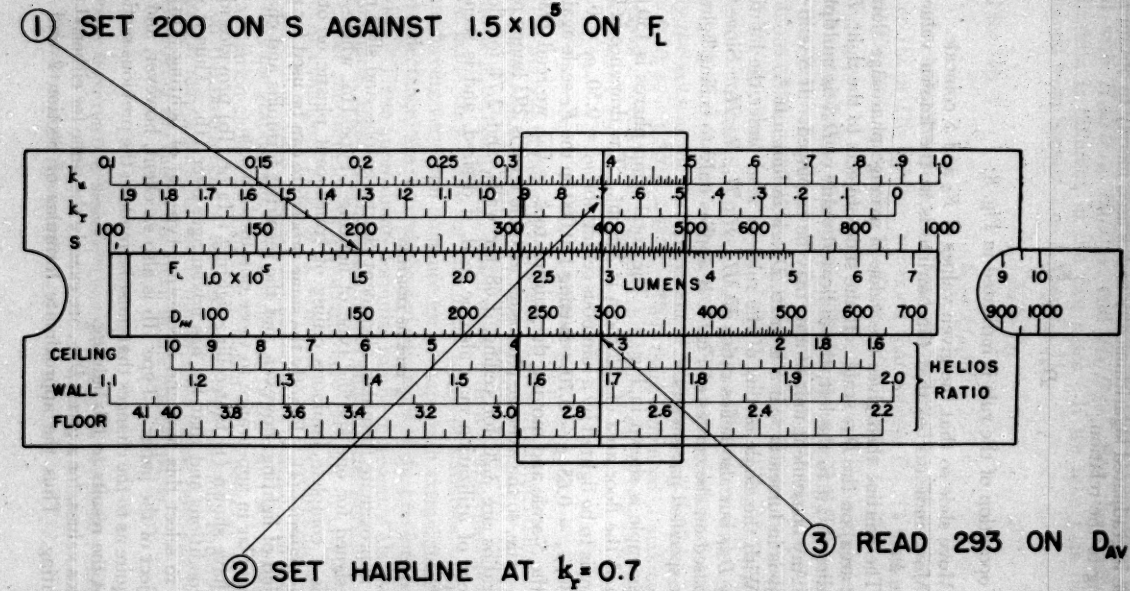

FIG. 8. Example of use of the slide rule. Total lamp lumens = 150,000, floor area = 200 m², domance = 0.70. Resulting pharosage is 293 lumen m⁻².

The slide is graduated logarithmically and is used merely to obtain D_{AV} according to the relation,

$$D_{AV} = k_r \frac{F_L}{S}.$$

The operation of the rule is indicated in Fig. 8:

(1) Move slide so that the given values of F_L and S coincide.

(2) Move indicator so that the hairline is at the known value of domance k_r.

(3) The hairline then gives the value of average pharosage (lumen per unit area) on the D_{AV} scale. If the slide projects to the right, D_{AV} is read directly; if to the left, the indicated value of D_{AV} is multiplied by 10. Any convenient unit of area may be employed. If S is in m^2, then D_{AV} is in lumen m^{-2}; if S is in ft^2, D_{AV} is in lumen ft^{-2}.

(4) With the single setting of the rule, we read under the hairline, not only D_{AV} but also helios ratios H_2/H_A, H_A/H_1, H_A/H_3. Since the rule is based on the curves of Fig. 6, it applies only to ceiling lighting with the specified parameters.

An example is shown in Fig. 8. The total lamp pharos is 150,000 lumen and the floor area of the room is 200 m^2. The domance is 0.7. The room is to be lighted by a luminous ceiling and $\rho_1 = 0.50$, $\rho_2 = 0.70$, $\rho_3 = 0.30$, $\rho_A = 0.65$, $g = 0.70$. Setting 150,000 on the F_L-scale against 200 on the S-scale and moving the hairline to $k_r = 0.7$, we read 293 on the D_{AV}-scale, so the average pharosage at table level is 293 lumen m^{-2}. Helios ratios are 3.20 for ceiling, 1.68 for walls, and 2.74 for floor. Coefficient of utilization may also be read, if desired, and is seen to be 0.392.

6. TYPE IIb LIGHTING

The approximate formulas, alignment charts, graphs, and slide rule were designed for one specific type of lighting—Type IIa, where the source is a complete luminous ceiling of translucent plastic or other diffusing material (4). Exactly the same procedure can be used for any other kind of lighting, however, and the resulting formulas and charts will be similar in appearance to those obtained for IIa.

We have shown (1) that ceiling lighting (IIa or IIb) provides ideal visual conditions and that IIa has advantages over IIb. Thus it was natural to select this new and interesting type (6) of lighting (IIa) as the subject of the paper. Type IIb is also excellent, however, and we next inquire as to the changes that must be made in the previous sections to adapt the results to IIb lighting.

Helios values, for a given D_{AV}, are exactly the same for either IIa or IIb lighting. Thus the approximate formulas of Section 2 and the

alignment charts of Section 3 apply to all Type II lighting, when we deal with H_{1M}/D_{AV}, H_2/D_{AV}, and H_3/D_{AV}. But the coefficient of utilization is different in the two cases. If we take f as the value obtained from Section 2 or 3, then for IIa,

$$k_u = fg, \tag{10}$$

and for IIb,

$$k_u = (f\rho_2)g. \tag{11}$$

We conclude, therefore, that Sections 2 and 3 apply equally well to either IIa or IIb lighting, provided that we use Eq. 11 instead of the usual Eq. 10 in computing coefficient of utilization for IIb.

Equations 10 and 11 show that the luminous indirect system (IIb) would always be less efficient than the luminous ceiling (IIa) were it not for the fact that the indirect fixture has a higher logance g than the luminous ceiling, and the ceiling reflectance for IIb can be made higher than the apparent reflectance of the luminous ceiling. These effects tend to compensate. In fact, if we take a IIb system with $\rho_1 = 0.50$, $\rho_2 = 0.80$, $\rho_3 = 0.30$, $g = 0.84$, we find that the results are almost exactly the same as for the IIa system of Sections 4 and 5 with $\rho_1 = 0.50$, $\rho_2 = 0.70$, $\rho_3 = 0.30$, $g = 0.70$. Thus there is no need of making special graphs or a special slide rule for IIb lighting: *all the results of this paper apply equally well to either IIa or IIb lighting.*

7. SUMMARY

The purpose of the paper has been to present simplified methods that will expedite the calculation of ceiling lighting (Type II). Approximate formulas have been given, which allow ordinary slide-rule calculations to be made very easily for the usual range of variables. Only with rooms having very high domance (or perhaps with extraordinarily high floor reflectance) are the complicated equations of the previous paper (1) needed. These approximate formulas can be represented also by alignment charts, Figs. 2 to 5, which further simplify the work.

Either the formulas or the charts may be used to investigate the effect of a change in ρ_1, ρ_2, or ρ_3. However, if reflectances are standardized at recommended values, other methods are possible. In particular, one may use graphs (Fig. 6) or a slide-rule (Figs. 7 and 8). The method of calculation chosen for a specific problem will depend on the problem and on the preferences of the designer. The previous equations and tables (3) may always be used; but in most cases, time can be saved by employing the short-cuts given in the present paper.

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(3) PARRY MOON AND D. E. SPENCER, *Lighting Design*, Cambridge, Mass., Addison-Wesley Press, 1948.

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ON THE THEORY OF ANGULAR CORRELATION PHENOMENA

BY

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ABSTRACT

The correlation distribution function for emissions of non-relativistic particles in two successive disintegrations of a system is calculated without the use of perturbation theory and without particular assumptions for the nature of the "interactions" responsible for the transitions. The calculation is limited to transitions with the emission of only one particle (or more precisely, the disintegration of a quasi-stationary system into two sub-systems). Some general properties of correlation distribution functions are obtained. Also the number of undetermined parameters which enter the distribution function is counted under important restricting conditions. The form of the calculation makes possible the exhibition of the formal identity of the correlation distribution function with the angular distribution function for resonance reactions. Both distribution functions may be represented as polynomials in $\cos^2\theta$ of degree not greater than J, where J is the spin of the intermediate states of the two processes.

INTRODUCTION

Angular correlation distribution functions have been calculated for a number of specific cases by various writers,[2] and general properties of the correlation functions have been investigated by group-theoretical methods.[3] The present paper provides a somewhat different approach to the problem from those previously employed. The calculation which follows is based on formal expressions for the quasi-stationary states of the systems involved in the correlation experiment (Eq. 11) and makes no use of perturbation theory. Also no question of the nature of the "interactions" which cause the disintegrations of the unstable states enters the discussion except insofar as knowledge of this interaction limits the number of the unknown parameters which appear in the final results. Thus, the role of the angular momentum quantum numbers is made to stand out sharply.

The form of the calculation employed in this paper is useful for the following reasons. It provides explicit results for the correlation functions insofar as these may be obtained from a knowledge of the quantum numbers of the states involved and, at the same time, presents these results in such form that the general properties of the distributions are readily obtained. Also it makes possible the exhibition of the close formal relation between the correlation distribution and the angular distribution functions for the products occurring in resonance reactions.

Section 2 below has as its object the introduction of the quasi-stationary state wave functions in a form appropriate for our purposes.

[1] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[2] D. R. HAMILTON, *Phys. Rev.*, Vol. 58, p. 122 (1940); G. GOERTZEL, *Phys. Rev.*, Vol. 70, p. 897 (1946); D. L. FALKOFF, Doctoral Dissertation, University of Michigan (1948).

[3] C. N. YANG, *Phys. Rev.*, Vol. 74, p. 764 (1948).

The investigation of the correlation distribution function begins with Section 3.

2. QUASI-STATIONARY STATES

The stationary states of a system, C, at energy E are provided by the solutions of the Schroedinger equation

$$H\Psi = E\Psi, \tag{1}$$

where H is the Hamiltonian operator for the system. The configuration space over which Ψ is defined may be divided into two parts which we shall call the "internal" and "external" regions.[4] All points of the external region (with which we shall be mainly concerned) represent configurations in which the total system C is divided into two or more "sub-systems" separated by distances greater than the range of nuclear forces. Let the total energy of the system C be consistent with its appearance in the form of two completely separated stable sub-systems, A_s, B_s ($C = A_s + B_s$) moving with a relative kinetic energy E_s (wave number k_s). E_s is related to E through $E = E_s + Q_s$, where Q_s is the internal energy of the A_s, B_s sub-systems. The part of the externa region of configuration space which represents C in the form of separated A_s, B_s sub-systems will be referred to as the "s channel." (If the sizes of sub-systems are neglected, only the vector coordinate $\mathbf{r}_s$, representing the position of A_s relative to B_s, varies within this channel. The wave equation (1) becomes, in the s channel (center of mass of system at rest)

$$\left\{H_s - \frac{\hbar^2}{2m_s}\nabla_s^2 + V_s\right\}\Psi = E\Psi \quad (s \text{ channel}), \tag{2}$$

where H_s is the Hamiltonian for the A_s, B_s sub-systems ($-\hbar^2/2m_s)\nabla_s^2$ is the operator for the relative kinetic energy, V_s is the potential energy of the pair of sub-systems. (V_s is either a coulomb potential if A_s, B_s are charged, or zero if one of the sub-systems is neutral.) Particular solutions of (2) may be taken in the form

$$(|j\mu s)P_m^l(\theta_s, \phi_s)T_{ls}^{\pm}(r_s) \equiv [lmj\mu s]_{\pm} \tag{3}$$

$$T_{ls}^{\pm}(r_s) \to (\pm iv_s^{\frac{1}{2}}r_s)^{-1}\exp(\pm ik_s r_s). \tag{3a}$$

(The $[lmj\mu s]_{\pm}$ symbols are defined by Eq. 3.[5] Here the $(|j\mu s)$ represents a normalized wave function for the pair of sub-systems A_s, B_s, and is that wave function for which the resultant of the spin angular momenta of the two sub-systems is specified by the quantum number j and the Z component of this resultant spin angular momentum (along an

[4] For a more complete discussion of the internal and external regions and of the further characteristics of the solutions of (1) see E. P. WIGNER and L. EISENBUD, *Phys. Rev.*, Vol. 76, p. 29 (1947).

[5] Square brackets about a set of indices indicate a solution of the wave equation in the *external* region characterized by the contained indices.

arbitrarily chosen Z axis) is defined by the quantum number μ; the s index is used to specify the pair of sub-systems A_s, B_s. The P^l_m are normalized eigenfunctions of the angular momentum operators.[6] The $T^{\pm}_{ls}$ represent a particular pair of solutions of the radial wave equation which arises from (2), for the relative motion of the sub-systems. The two solutions, which are completely defined by the asymptotic forms (3a), represent outgoing (+ superscript) and incoming (− superscript) spherical waves normalized to unit current. Arbitrary solutions of the wave equation (2) in the s channel may be written as a linear combination of the solutions (3).

We suppose that the energy E is, in general, consistent with the existence of the nuclear system C in the form of a variety of separated pairs of stable sub-systems ($A_s + B_s$, $A_{s'} + B_{s'}$, etc.) but not with the existence of three or more separated sub-systems. To each distinct pair of sub-systems—that is, to each index s, s', etc.—there will be an associated channel in the external region of the configuration space. The general solution of the Schroedinger equation (1) in the whole external region will thus be a linear combination of the solutions (3) extended over the various "occupied" channels (that is, channels which represent pairs of separated sub-systems which may exist at the energy E).

We shall be interested in states of the system C for which the total angular momentum (sum of resultant spin and orbital angular momentum) is definite. These may be obtained from linear combinations of the solutions (3). The coefficients which appear in these linear combinations are well known[7]

$$[JMljs]_{\pm} = \sum_{\mu m} s^{lj}_{J\mu m}[lmj\mu s]_{\pm}. \tag{4}$$

The $[JMljs]_{\pm}$ are solutions of (2) and again represent outgoing and incoming spherical waves normalized to unit current (the s coefficients form a unitary matrix). In (4) J is the total angular momentum quantum number and M is the quantum number associated with the Z component of total angular momentum. The s coefficients will be written later in the form

$$s^{lj}_{J\mu m} = (-)^{J+M}(2J+1)^{\frac{1}{2}} \begin{pmatrix} J & l & j \\ -\mu + m & m & \mu \end{pmatrix}. \tag{5}$$

The so-called 3-j-symbol[8] (the bracketed symbol on the right of (5)) possesses certain symmetry properties which makes its introduction

[6] For the specific character of the normalization of the $(|j\mu s)$ and the P^l_m see Eqs. 3 and 7 of Footnote 4.

[7] These coefficients are explicitly given in Chapter XII of "Gruppentheorie," E. P. WIGNER, Ann Arbor, Edwards Brothers (1944). The notation for the s coefficients is taken from this reference. See also Chapter II of "Theory of Atomic Spectra," E. U. CONDON AND G. H. SHORTLEY, New York, Macmillan Co. (1935).

[8] I am indebted to Professor Wigner for the information given here on the properties of the 3-j-symbols.

useful. These are given by

$$\begin{pmatrix} j_1 & j_2 & j_3 \\ m_1 & m_2 & m_3 \end{pmatrix} = (-)^{j_1+j_2+j_3} \begin{pmatrix} j_2 & j_1 & j_3 \\ m_2 & m_1 & m_3 \end{pmatrix}$$
$$= (-)^{j_1+j_2+j_3} \begin{pmatrix} j_1 & j_2 & j_3 \\ -m_1 & -m_2 & -m_3 \end{pmatrix}. \quad (6)$$

From its definition, it is clear that the 3-j-symbol is zero unless the sum of its lower indices is zero.

Particular solutions of the Schroedinger equation in the external region may be taken in the form

$$[\Psi^{JM}_{ljs}] = [JMljs]_- + \sum_{l'j's'} c_J(l'j's';ljs)[JMl'j's']_+. \quad (7)$$

The left part of the solution given by the right of (7) represents a single incoming spherical wave of the s pair of sub-systems of the type (4). As a consequence of the collision between the s sub-systems, a variety of outgoing spherical waves arise; these are indicated on the right of (7). For arbitrary values of the c_J coefficients, which determine the amplitudes of the outgoing waves, (7) is a solution of (1) in the external region, since it is a linear combination of solutions of the type (4). If the c_J coefficients are appropriately chosen, (7) can be made to represent the external *part* of a solution Ψ of (1) valid over the whole of configuration space. In the following, we shall look upon (7) as a part of a full solution Ψ^{JM}_{ljs} of (1). Thus, the c_J coefficients are no longer arbitrary but definite energy dependent quantities which can be determined in general only by a complete solution of the full Schroedinger equation.[9]

The c_J coefficients form a unitary matrix—the "collision matrix"—(rows and columns specified by the l, j, s indices). The unitary character of the matrix expresses the equality of incoming and outgoing currents in the states (7).[9] The c_J matrix possesses eigenvalues and eigenvectors which we shall denote by c^κ and x^κ (with components x^κ_{ljs}) respectively.[10] A J index should accompany these symbols but we shall suppress it if no ambiguity results. By linear combinations of (7) we may form the states

$$[(|JM)^\kappa] = \sum x^\kappa_{ljs}\{[JMljs]_- + c^\kappa[JMljs]_+\}. \quad (8)$$

The c^κ which are the eigenvalues of the unitary matrix c_J are of unit absolute amplitude and may be written $\exp(2i\delta_\kappa)$. The δ_κ may be considered as generalizations of the phase shift which appears in the analysis of scattering by a potential field.[11] When the c_J matrix is one-dimensional, the associated δ is the usual phase shift.

[9] For more detailed justification of solutions of the type (7) and further treatment of the collision matrix see footnote (4) and the reference provided there.

[10] A discussion of the proper values of the collision matrix is given by W. KOHN, *Phys. Rev.*, Vol. 74, p. 1763 (1948).

[11] N. F. MOTT AND H. S. W. MASSEY, "Theory of Atomic Collisions," Oxford, 1949, Chapter II.

The c_J matrix and hence the c^κ and x^κ will depend on the energy. In certain energy regions—the "resonance regions"—one of the δ_κ varies relatively rapidly with energy. It is this rapid rise which provides the resonance phenomena. Analysis shows that the $|x^\kappa_{l\beta}|^2$ are proportional to the "partial widths" of the resonance level. The $x^\kappa_{l\beta}$ are not sensitive functions of the energy in the resonance region.

A quasi-stationary state may be built out of a linear combination of the states (8) over a region of energy covering the resonance. For this purpose it is necessary to employ that one of the states $(|JM)^\kappa$ which exhibits the resonance characteristics. Assuming this to be the case, we may write

$$[(|JM)_q{}^\kappa] = \int_0^\infty (|JME)^\kappa e^{-iEt/\hbar} g(E)dE, \tag{9}$$

where $g(E)$ may be qualitatively described as a function with maximum at the energy at which δ_κ is most rapidly varying, and which is relatively large only over the resonance region. If we separate out the only energy dependent part of $[JMljs]_\pm$ by writing

$$[JMljs]_\pm = \{JMljs\} T^\pm_{ls} \rightarrow \{JMljs\}(\pm ir_s v_s^{\frac{1}{2}})^{-1} \exp(\pm ik_s r_s), \tag{10}$$

which is a defining equation for the $\{JMljs\}$ symbols, we have, for the quasi-stationary state (9)[12]

$$[(|JM)_q] \rightarrow \sum \bar{x}_{lj_s}\{JMljs\} Q_s(r_s, t), \tag{11}$$

where

$$Q_s(r_s, t) \rightarrow i r_s^{-1} \int v_s^{-\frac{1}{2}}(e^{-ik_s r_s} - e^{2i\delta_\kappa} e^{ik_s r_s}) g(E) e^{-iEt/\hbar} dE \tag{11a}$$

(the distinguishing κ superscript has been dropped). In this integration it was assumed that the slowly varying coefficients x_{lj_s} could be taken out of the integral as the *constants* $\bar{x}_{lj_s}$.

Equation 11, for the quasi-stationary state specified by definite angular momentum quantum numbers, forms the basis for the development which follows. Since we shall be concerned only with angular distributions, we need not investigate further the nature of the radial time dependent functions Q_s. What we shall be able to say about the correlation distribution functions is obtained from our knowledge of the $\{JMljs\}$ functions. We cannot, in general, give a complete characterization of the distribution because of the presence of the unknown coefficients $\bar{x}_{lj_s}$.

3. THE CORRELATION DISTRIBUTION FUNCTION

The angular correlation experiments deal with the measurement of the relative distribution of the products of *two consecutive* disintegrations of a system. The physical processes involved may be described as follows. A system is formed in a quasi-stationary state with angular

[12] The subscript q is employed to designate the quasi-stationary character of the state described.

momentum quantum number I (spin). It is presumed that this state is formed by spatially symmetric processes, so that all the components of the angular momentum of the system along an arbitrarily chosen axis are equally probable. If we designate the quantum number for the component along some chosen direction, Z, by L, our supposition is that the probability of the component L in the quasi-stationary state is independent of L. This specifies the initial condition of the system. It is supposed, further, that this quasi-stationary state of the system decays with the possible emission of particles of several types. The occurrence of a particular type of particle with a definite spin, characterized by a spin quantum number j, and definite energy (or more precisely, a definite small range of energy) in some given direction is measured. We suppose the residual system (that remaining after the emission of the particle j[13]) has a total angular momentum quantum number, J, and is itself quasi-stationary. This system in turn decays with the emission of particles, and the correlation experiment is designed to measure the occurrence of a particular type characterized by spin quantum number h with a definite small range of energy in a direction making an angle θ with the emission of the particle j; the emission of h results in a second residual nucleus with spin quantum number K. The frequency of the occurrence of the particle h (after the emission of j) is measured as a function of the angle θ, providing the distribution $W(\theta)$. We seek now to calculate $W(\theta)$ in terms of the angular momentum quantum numbers which occur in the process and the relevant properties of the quasi-stationary states.

A word of justification is required for our treatment of W as a function of θ alone. The initial condition of the system is spherically symmetrical. After the emission of j, the symmetry of the system is axial about the direction of the emission. If we take a co-ordinate system with Z axis along this axis of symmetry, the distribution function W will clearly be independent of the azimuthal angle ϕ. It has been assumed implicitly, of course, that the j particle is recorded by the measuring apparatus, no matter what the orientation of its total angular momentum. If only the j particles in a definite state of polarization are measured, the symmetry of the whole problem may no longer be axially symmetrical and it will, in general, be necessary to deal with a function $W(\theta, \phi)$ rather than $W(\theta)$.

A. The Emission of the j Particle

It will be convenient, for reasons indicated above, to take the Z axis along which components of angular momentum are measured in the

[13] It will be useful to use the same symbol, for example, j, to specify the spin angular momentum of the particle *and* the particle itself.

direction of the emission of j. The wave function for quasi-stationary states with quantum numbers I, L, may be written (Eq. 11)

$$[(|IL)_q] \rightarrow \sum_{l'j's'} \bar{x}_{l'j's'}\{ILl'j's'\}Q^I_{s'}(r_{s'}, t). \tag{12}$$

By Eqs. 10, 4, 5

$$\{ILj'l's'\} = (-)^{I+L}(2I+1)^{\frac{1}{2}} \sum_{\mu'm'} \begin{pmatrix} I & j' & l' \\ -L & \mu' & m' \end{pmatrix} P^{l'}_{m'}(|j'\mu's'). \tag{13}$$

The $(|j'\mu's')$ may be written as a linear combination of the wave functions $(|JM)$ and $(|j\mu)$ for the component sub-systems. The angular momentum combination rules provide

$$(|j'\mu's') = (-)^{j'+\mu'}(2j'+1)^{\frac{1}{2}} \sum_{M\mu} \begin{pmatrix} j' & J & j \\ -\mu' & M & \mu \end{pmatrix} (|JM)(|j\mu). \tag{14}$$

Here the $P^{l'}_{m'}$ represents the angular part of the wave function for the relative motion of the systems $(|j\mu)$ and $(|JM)$, the emitted and residual systems, respectively, which are defined by the index s'; J and j are, of course, fixed given numbers.

In the construction of the quasi-stationary state $(|IL)_q$ we have treated the sub-system $(|JM)$ as though it were itself stationary. By hypothesis, this is not the case, since we presume that the J system decays (that is, is itself quasi-stationary) with the emission of the h particle among others. It is not necessary, however, to concern ourselves with this complication. It must be presumed that it is permissible to consider the $(|JM)$ sub-system as stationary insofar as its emission from the initial $(|IL)_q$ system is concerned. In fact, unless this is true, the notion of the *successive* emission of the j and h particles has no sense, and the breakup of the $(|IL)_q$ must be considered as a decay into three sub-systems rather than two.

The j particle is emitted by hypothesis along the direction Z. To determine the wave function of the residual system after the observation of j, we expand the part of (12) dealing with the relative motion of the emitted sub-systems into plane waves. The coefficient of the wave describing the emission of the particle in the Z direction will then be the wave function for the residual system. The expansion of a particular term in (12) may be written

$$P^{l'}_{m'}Q_{s'} = \int e^{i(\mathbf{k}_{s'}\cdot\mathbf{r}_{s'})}\phi_{l'm's'}(\mathbf{k}_{s'}, t)d\mathbf{k}_{s'}. \tag{15}$$

This can be considered as a unitary transformation between the state $\phi_{l'm's'}$ in a momentum representation and the state $P^{l'}_{m'}Q_{s'}$ in a coordinate representation. Since the latter state is an eigenstate of the angular momentum operators, the ϕ must also be such an eigenstate. As the angular momentum operators are of the same form in both

representations, we must have

$$\phi_{l'm's'} = g_{s'}(k_{s'}, t)P^{l'}_{m'}(\chi_{s'}, \omega_{s'}), \tag{15a}$$

where $\chi_{s'}$, $\omega_{s'}$ define the direction of $\mathbf{k}_{s'}$ in the same sense that $\theta_{s'}$, $\phi_{s'}$ define the direction of $\mathbf{r}_{s'}$. The coefficient of $\exp i(\mathbf{k}_{s'}, \mathbf{r}_{s'})$ for $\mathbf{k}_{s'}$ in the direction of the Z axis is thus[6]

$$g_{s'}(k_{s'}, t)P^{l'}_{m'}(0, \omega_{s'}) \propto g_{s'}(k_{s'}, t)(2l' + 1)^{\frac{1}{2}}\delta_{m',0}. \tag{16}$$

In writing (16) constant factors in the $P^{l'}_{m'}$ have been dropped.

On making use of Eqs. 16, 13, and 14 we have, for the part of the wave function which governs the probability of finding the system $(|j\mu)$ moving along the direction of the Z axis,

$$\left\{\sum_{l'j'} \bar{x}_{l'j's'} \sum_{\substack{M\mu \\ \mu'm'}} (-)^{j'+\mu'+L}(2j' + 1)^{\frac{1}{2}}(2l' + 1)^{\frac{1}{2}}\delta_{m',0} \right.$$
$$\left. \times \begin{pmatrix} I & j' & l' \\ -L & \mu' & m' \end{pmatrix} \begin{pmatrix} j' & J & j \\ -\mu' & M & m \end{pmatrix} (|JM)(|j\mu)\right\} \int g_{s'}e^{ik_{s'}z_{s'}}dk_{s'}. \tag{17}$$

(The constant factor $(-)^I(2I + 1)^{\frac{1}{2}}$ has been omitted as it is irrelevant for what follows.) The integral factor determines the probability of finding the $(|j\mu)$ sub-system along the Z axis with a given separation $z_{s'}$ at any time t. After the detection of the $(|j\mu)$ system, the wave function for the residual system with spin quantum number J is

$$\phi^{L\mu} = \sum_{j'l'} \bar{x}_{l'j's'}(2j' + 1)^{\frac{1}{2}}(2l' + 1)^{\frac{1}{2}} \sum_{M} (-)^{(j'+2L)}$$
$$\times \begin{pmatrix} I & j' & l' \\ -L & L & 0 \end{pmatrix} \begin{pmatrix} j' & J & j \\ -L & M & \mu \end{pmatrix} (|JM). \tag{18}$$

This is obtained from (17) by taking the sums over m' and μ' and dropping the $(|j\mu)$ and integral factors. Of course, the μ is not, in fact, measured and we should deal with the wave function (17) (after dropping the dependence on z). However, since the $(|j\mu)$ states for different μ are orthogonal, we may proceed with (18) if we sum all final results over the index μ.

Equation 18 provides the wave function for the residual system (after observation of $(|j\mu)$ system in Z direction) for the initial state $(|IL)_q$ of (12). Our initial state is not (12), however, but a mixture of these states with different L. Also the μ quantum number is not determined. Hence the state of the residual system may be considered as a *mixture* of the states $\phi^{L\mu}$; the weight factors for the different states are all equal. Since the 3-j-symbol is zero unless the sum of its lower indices is zero, the sum over M in (18) reduces to only one term for $M = L - \mu$. Thus, for each value of L and μ the residual system is characterized by a definite value of M, and the mixture of $\phi^{L\mu}$ states may be replaced by a mixture of $(|JM)$ states. If we write Eq. 18 in

the form

$$\phi^{L\mu} = \sum A_M^{L\mu}\delta_{M,\,L-\mu}(|JM) = \sum A_M^{L\mu}\delta_{\mu,\,L-M}(|JM)$$

the weight of the $(|JM)$ state is proportional to

$$p(M) = \sum_L |A_M^{L,L-M}|^2$$

that is, to

$$p(M) = \sum_L \left| \sum_{j'\nu} (-)^{s'+2L}\bar{x}_{l'j's'}(2j'+1)^{\frac{1}{2}}(2l'+1)^{\frac{1}{2}} \times \begin{pmatrix} I & j' & l' \\ -L & L & 0 \end{pmatrix} \begin{pmatrix} j' & J & j \\ -L & M & L-M \end{pmatrix} \right|^2. \quad (19)$$

The fact that the mixture over L and μ may be replaced by a mixture over M with the weights specified by (19) makes possible a simplification of the calculation of the results of experiments on the residual system. We may calculate the results for each M separately and then average over M with weights as given by (19). Thus, if the distribution of the h particles for an initial state $(|JM)$ is $W_M(\theta)$, the desired distribution is

$$W(\theta) = \sum_M p(M)W_M(\theta). \quad (20)$$

B. The Emission of the h Particle

The decay of the J system may be treated in a manner similar to that given above for the decay of I. We must, of course, now take into account the fact that the $(|JM)$ sub-system is quasi-stationary and is itself defined by an equation similar to (12):

$$[(|JM)_q] \to \sum_{l'j's'} \bar{y}_{l'j's'}\{JMl'j's'\}Q_{s'}^{l'}. \quad (21)$$

On making use of an expansion similar to (13) and restricting ourselves to the consideration of a particular pair of sub-systems, s', (21) becomes

$$Q_{s'} \sum_{l'j'} \bar{y}_{l'j's'}(-)^{J+M}(2J+1)^{\frac{1}{2}} \sum_{m'} \begin{pmatrix} J & j' & l' \\ -M & \mu' & m' \end{pmatrix} P_{m'}^{l'}(|j'\mu's'). \quad (22)$$

The *relative* probability of observing the systems in a given solid angle about the direction $\theta_{s'}$, $\phi_{s'}$ is given by the absolute square of (22) integrated over the internal coordinates of the sub-systems. Since the different $(|j'\mu's')$ are orthogonal, we get (on dropping constant factors)

$$W_M(\theta) = \sum_{j'\mu'} \left| \sum_{l'm'} \bar{y}_{l'j's'} \begin{pmatrix} J & j' & l' \\ -M & \mu' & m' \end{pmatrix} P_{m'}^{l'} \right|^2. \quad (23)$$

(The $Q_{s'}$ factor depends only on r and t and thus does not affect the distribution in angle.) If s' refers to the h sub-system, (23) represents the distribution of the h particle from the quasi-stationary state $(|JM)_q$.

C. The Correlation Function

The dependence of the probability of the observance of j along the Z axis and the observance of h along a line making an angle θ with the Z axis is given by (20), with W_M from (23) and $p(M)$ from (19).

We shall now investigate some general properties of $W(\theta)$. We note first that the distribution depends in general for its details on more than just the angular momentum quantum numbers involved. The coefficients x and y, which are associated with the partial widths of the quasi-stationary level, enter the final expressions. There is a circumstance, however, under which the distribution function may be made explicit. If the states I and J are such that only one of the $x_{l'j's'}$ and $y_{l'j's'}$ is of importance, then the sums over j' and l' drop out in (18) and (22). As a consequence, the $p(M)$ and the $W(M)$ are completely defined to within constant (and consequently irrelevant) factors. Under these circumstances $W(\theta)$ is given by

$$W(\theta) = \sum_M \left\{ \sum_L (-)^{2L} \left| \begin{pmatrix} I & j' & l' \\ -L & L & 0 \end{pmatrix} \begin{pmatrix} j' & J & j \\ -L & M & L-M \end{pmatrix} \right|^2 \right\} \times \left\{ \sum_{\mu''} \left| \begin{pmatrix} J & j'' & l'' \\ -M & \mu'' & M-\mu'' \end{pmatrix} P^{l''}_{M-\mu''} \right|^2 \right\} \quad (24)$$

(only the $\bar{x}_{l'j'}$ and $\bar{y}_{l''j''}$ terms are considered different from zero). We shall deal with the further reduction of this result later. The occurrence of only one $j'l'$ in the expansions of (13) and (21) is generally described by stating that a selection rule exists for the transition from the quasi-stationary state to the state of the system describing the emitted particles. The situation described by (24) is the one usually discussed in the literature on this subject. Its application to specific problems should be useful for the empirical determination of selection rules and angular momentum quantum numbers of nuclear systems.

When several of the $\bar{x}_{l'j's'}$ or $\bar{y}_{l'j's'}$ are important, the correlation function cannot be given explicitly without a knowledge of these numbers. However, some general properties of $W(\theta)$ may be deduced. It is easily shown that $p(M) = p(-M)$ and that similarly $W_M(\theta) = W_{-M}(\theta)$. From (23) we have

$$W_M(\theta) = \sum_{j'\mu'} \sum_{\substack{l'l'' \\ m'm''}} \bar{y}_{l'j's'} \bar{y}^*_{l''j's'} (-)^{2M} \times \begin{pmatrix} J & j' & l' \\ -M & \mu' & m' \end{pmatrix} \begin{pmatrix} J & j' & l'' \\ -M & \mu' & m'' \end{pmatrix} P^{l'}_{m'} P^{l''*}_{m''}. \quad (25)$$

If we change the sign of M and at the same time change the signs of the summation indices μ', m', m'', we get (on making use of Eq. 6) the same sum as appears in (25) with an extra factor of the form $(-)^{2(J+l')}(-)^{l'+l''}$. Since $J + j'$ is always an integer, the $(-)^{2(J+j')} = 1$.

By the parity rule, the various l' indices which appear in the summation in (21) are either all even or all odd, depending on the parity of the J state and the parity of sub-systems into which the J system decays. As a consequence $l' + l''$ is always even and $(-)^{l'+l''} = 1$. A similar calculation based on similar arguments shows that $p(M) = p(-M)$. These results may be used to simplify the correlation function calculation a little.

A further simplification may be effected by making use of the fact that

$$\sum_M W_M(\theta) = \text{const.} \tag{26}$$

This may be seen directly from (25). Since the coefficients of (5) form a unitary matrix, we have

$$\sum_{M\mu'} (2l'+1)^{\frac{1}{2}}(2l''+1)^{\frac{1}{2}} \begin{pmatrix} J & j' & l' \\ -M & \mu' & m' \end{pmatrix} \begin{pmatrix} J & j' & l'' \\ -M & \mu' & m'' \end{pmatrix} = \delta_{l'l''}\delta_{m'm''}. \tag{27}$$

Thus, upon summation of (25) over M, and making use of (27), we obtain

$$\sum W_M(\theta) = \sum_{j'l'} (2l'+1)^{\frac{1}{2}} |\bar{y}_{l's's}|^2 \sum_{m'} |P^{l'}_{m's}|^2. \tag{28}$$

The last sum of (28) is independent of θ, φ. That (26) is true should be evident on general grounds since it represents the distribution of the s' systems as a function of angle from a *spherically symmetric* state. For the correlation function we may write

$$W(\theta) = \sum [p(M) - p(J)]W_M(\theta) + p(J) \sum W_M(\theta).$$

If we normalize the $W_M(\theta)$ so that $\sum_M W_M(\theta) = 1$, we have

$$W(\theta) = \sum [p(M) - p(J)]W_M(\theta) + p(J). \tag{29}$$

Thus the calculation of W_θ requires the calculation of the $p(M)$ and the $W_M(\theta)$ for $M = 0, 1, \cdots J - 1$.

The general form of the function $W(\theta)$ depends only on the quantum number J. In fact, each $W_M(\theta)$ may be expressed as a polynomial in $\omega = \cos^2\theta$, the highest power of ω occurring in the polynomial being J or less. If, instead of choosing the Z axis, as was done in (21), a different choice is made, we have

$$[JMl'j's']_+ = \sum_M \kappa_M [JMl'j's']'_+,$$

where the prime on the bracket on the right indicates that the states referred to are expressed in the *new* co-ordinate system. We shall not need to consider the values of the coefficients, κ_M, which will depend on the orientation of the new co-ordinate system. With the use of (30) in the development following (21) we get, for the distribution $W_M(\theta')$

(referred to the new co-ordinate frame):

$$W_M(\theta') = \sum_{j'\mu' l' l''} \bar{y}_{l'j'\mu'} \bar{y}^*_{l''j'\mu'} \sum_{\substack{MM' \\ m'm''}} \kappa_M \kappa^*_{M'} (-)^{M+M'} \times \begin{pmatrix} J & j' & l' \\ -M & \mu' & m' \end{pmatrix} \begin{pmatrix} J & j' & l'' \\ -M & \mu' & m'' \end{pmatrix} P^{l'}_{m'} P^{l''}_{m''}. \quad (31)$$

The product $P^{l'}_{m'} P^{l''*}_{m''}$ may be expanded similarly. We may write in general

$$P^{l'}_{-m''} P^{l'}_{m'} = \sum_{l'''} \alpha_{l'l''} P^{l'''}_{m'-m''}, \quad (32)$$

where the $\alpha_{l'l''}$ coefficients, which are, of course, related to the 3-j-symbols, need not be further specified. Two features of the expansion (31) with the substitution of (32) should be noted. Since by the parity rule l' and l'' are either both even or both odd, the parity of the product on the left of (32) is always even so that the l''' on the right must be even. Second, the values of the Z' component of orbital angular momentum which appear will depend on the orientation of the Z' axis and all values of the Z' components consistent with the orbital quantum numbers l''' which arise in the distribution may arise by a suitable choice of the Z' axis. On the other hand, the maximum value of $m' - m''$ for arbitrary location of the new Z axis measures the maximum l''' which appears in the distribution. Since the 3-j-symbols are zero unless the sum of the lower indices is zero, we have

$$m' = M - \mu', \qquad m'' = M' - \mu', \qquad m' - m'' = M - M'.$$

As the M and M' take on values from $-J$ to J, the maximum value of $m' - m''$ is $2J$, which is, as a consequence of the argument above, the maximum value of l'''. The values of the orbital angular momenta are not affected, of course, by the co-ordinate transformation, so that, for $W_M(\theta)$ in the original frame, we may write

$$W_M(\theta) = \sum_l \gamma_l P^l_0(\theta), \quad (33)$$

in which only even values of l occur and the maximum value of l is $2J$ or smaller. (That the m is zero for the co-ordinate frame chosen is readily seen from (25). Examination of the 3-j-symbols shows that $m' = m''$, or $m' - m'' = 0$.) The correlation function $W(\theta)$ is a weighted average of the $W_M(\theta)$ and is, therefore, of the same form as that given by (33).

D. The Undetermined Coefficients

If the number of coefficients $\bar{x}$ and $\bar{y}$ in the $p(M)$ and $W_M(\theta)$ (which depend on the details of the wave functions of the systems involved) is large, the correlation function becomes relatively useless as a tool for the investigation of quantum numbers or selection rules. In general,

unless the spins of the various sub-systems are all zero, the number of undetermined coefficients which may in principle appear in the $W(\theta)$ is quite sizeable. However, under many circumstances, the number of coefficients which need be considered may be reduced by general arguments. These arguments are concerned with the nature of the coefficients as functions of the orbital angular momentum quantum number, l.

In the emission of radiation, for example, the probability of emission with different values of l decreases very strongly with increasing l (that is, increasing multipole order). Generally the lowest l value which is not prohibited by selection rules dominates and the higher possible l values may be neglected. This situation is not restricted to the case of the emission of radiation. The probability of emission with orbital quantum number l will be a rapidly diminishing function of l if the wave length of the emitted particle is large by comparison with the dimensions of the emitting system. It therefore seems worth while to consider the number of coefficients which may arise if the value of the l quantum number is defined. We shall do this for the $\bar{x}_{I'j'}$ coefficients which arise in the transition from the I system to the J, j systems. A similar analysis, of course, holds for the decay of the J system.

Our problem is to determine the number of values which j', the resultant of j and J, may have if the initial system has spin quantum number I and l' has some specified value. The quantum number j' must be consistent with the fixed quantum numbers I and l' on the one hand and the J and j on the other. Thus j' may have those values which are common to the sequences

$$I + L, \quad I + L - 1, \cdots, |I - L|,$$

and

$$J + j, \quad J + j - 1, \cdots, |J - j|.$$

The number of possible j' values is thus one greater than the difference between the smaller of the maxima and the greater of the minima of these sequences. This is given by the *smallest* one of the expressions

$$2L + 1, \quad 2I + 1, \quad 2J - 1, \quad 2j + 1,$$
$$I + L - |J - j| + 1, \quad J + j - |I - L| + 1.$$

Since the $\bar{x}$ and $\bar{\eta}$ coefficients appear as multiplicative factors, one of each set of them may always be taken out as a multiplicative factor.

4. THE RELATION OF THE ANGULAR DISTRIBUTION IN RESONANCE REACTIONS TO THE CORRELATION DISTRIBUTION

The problem of resonance reaction has a strong resemblance to the correlation problem. In the resonance reaction, two sub-systems with spins I and j (say) collide and are transformed so that systems with spins K and h are obtained from the reaction. We suppose that the colliding systems are prepared in a plane wave (unpolarized) moving along the Z axis and that the reaction proceeds through a resonance to

an intermediate state with angular momentum quantum number J. The general symmetry of this problem is the same as that met with in the correlation problem if the distribution of *unpolarized* h systems is measured. It is easily shown that the *form* of the angular distribution of the h particles is the same as that of the $W(\theta)$ obtained above if the so-called potential "scattering" is consistently omitted from consideration. There is, of course, no way of experimentally distinguishing between "resonance" and "potential" parts of a distribution. However, if the cross-section just outside the resonance region (which is ascribed to the "potential scattering") is small by comparison with the corresponding cross-section at the resonance, a fair approximation to the behavior of the reaction at resonance may be obtained by limiting the theoretical description to the resonance terms alone.

The plane incoming wave may be written, for a particular resultant spin j' (resultant of the spins j and I) with component μ', as a linear combination of incoming and outgoing spherical waves;

$$(|j'\mu's) \exp(ik_s z_s) \propto \sum_{l'} (2l' + 1)^{\frac{1}{2}} \{[l'0j'\mu's]_- + [l'0j'\mu's]_+\}, \quad (34)$$

where factors which will be of no consequence for the form of the distribution have been dropped. The actual incident wave is a uniform mixture of the waves (34) for all possible values of j' and μ'. The $[l'0j'\mu's]_\pm$ states may be expanded in terms of states for which the total angular momentum—the sum of the orbital and spin angular momenta—is definite.

$$[l'0j'\mu's]_\pm = \sum_{Jm} (-)^{J+M}(2J + 1)^{\frac{1}{2}} \begin{pmatrix} J & l' & j' \\ -M & 0 & \mu' \end{pmatrix} [JMl'j's]_\pm.$$

Thus the incoming spherical waves for a given $j'\mu'$ *and* J are described by

$$[\phi^{j'\mu'}]_i = \sum_{lM} (2l + 1)^{\frac{1}{2}}(-)^{J+M}(2J + 1)^{\frac{1}{2}} \begin{pmatrix} J & l' & j' \\ -M & 0 & \mu' \end{pmatrix} [JMl'j's]_-. \quad (35)$$

Let the collision sub-matrix be c_J for the J in question. Further, let the proper values of the collision matrix be c_J^κ (where the κ index is used to specify the proper value) and the components of the normalized proper vector associated with these proper values be x^κ_{ljs}. (The κ superscript runs over all values of ljs.) Then the stationary states of the system may be written

$$\sum x^\kappa_{l'j's'}\{[JMl'j's']_- + c_J^\kappa[JMl'j's']_+\}. \quad (36)$$

We may define a new set of states by the equation

$$\sum x^\kappa_{l'j's'}[JMl'j's']_\pm = [JM]^\kappa_\pm. \quad (37)$$

The individual states $[JMl'j's]$ may be expanded in terms of the $[JM]^\kappa$. Making use of the orthonormality of the proper vectors of the collision

matrix, we have

$$[JMl'j's]_{\pm} = \sum_{\kappa} (x^{\kappa}_{l'j's})^{*}[JM]^{\kappa}_{\pm}. \tag{38}$$

Thus, the incoming spherical waves of (35) become

$$\sum_{Ml'} (2l' + 1)^{\frac{1}{2}}(-)^{J+M}(2J + 1)^{\frac{1}{2}} \begin{pmatrix} J & l' & j' \\ -M & 0 & \mu' \end{pmatrix} \sum_{\kappa} (x^{\kappa}_{l'j's})^{*}[JM]^{\kappa}_{-}. \tag{39}$$

One of the proper values of the c_J matrix will have a variation with energy in the region considered which exhibits the resonance property (that is, we assume that the energy is such that there is resonance to a single level with quantum number J). The other proper values will be slowly varying functions of the energy and will contribute to the "potential scattering." We proceed now on the assumption that the contributions to the reaction from the latter proper values may be neglected, that is, we take only one term in the sum over κ in (39), that term in fact which provides the resonance. This procedure is equivalent to approximating all proper values except one by unity—the usual "pure resonance" approximation. We further assume, of course, that the $c_{J'}$ submatrices with $J' \neq J$ may all be approximated by unit matrices. With these assumptions, the *effective* incoming spherical waves (the remainder "experience" no interaction) are

$$\sum_{Ml'} (2l' + 1)^{\frac{1}{2}}(-)^{J+M}(2J + 1)^{\frac{1}{2}} \begin{pmatrix} J & l' & j' \\ -M & 0 & \mu' \end{pmatrix} (x^{\kappa}_{l'j's})^{*}[JM]^{\kappa}_{-}, \tag{40}$$

where c^{κ}_{J} is the only eigenvalue of the c_J matrix which differs appreciably from unity.

From (36) and (37) we see that the stationary states of the collision system may be given the form

$$[JM]^{\kappa}_{-} + c^{\kappa}_{J}[JM]^{\kappa}_{+}, \tag{41}$$

that is, for an incoming wave $[JM]^{\kappa}_{-}$ the associated outgoing wave is simply $c^{\kappa}_{J}[JM]^{\kappa}_{+}$. The outgoing waves arising from the incoming waves of (40) are thus obtained by changing the $[JM]^{\kappa}_{-}$ to $[JM]^{\kappa}_{+}$ and multiplying by c^{κ}_{J}. The "scattered waves" are obtained from these by subtracting the outgoing waves which arise for the case of no interaction, that is, for $c_J = 1$. For the *scattered waves* we have, therefore,

$$[\phi^{j'\mu'}]_{sc} = \sum_{Ml'} (2l' + 1)^{\frac{1}{2}}(-)^{J+M}(2J + 1)^{\frac{1}{2}} \times \begin{pmatrix} J & l' & j' \\ -M & 0 & \mu' \end{pmatrix} (x^{\kappa}_{l'j's})^{*}(c^{\kappa}_{J} - 1)[JM]^{\kappa}_{+}. \tag{42}$$

The scattered waves of (42) are those which arise from an incoming plane wave for which the resultant spin quantum numbers are j', μ'. The scattered waves from the unpolarized plane wave which represents

the initial state of the system is, therefore, a uniform mixture of the waves $[\phi^{j'\mu'}]_{sc}$. It is easily seen that this mixture may be replaced by an equivalent mixture of the $[JM]^+_+$ waves. Since the 3-j-symbol in (42) is zero unless $M = \mu'$, each $[\phi^{j'\mu'}]_{sc}$ is associated with a single $[JM]^+_+$. If, as in section (3A) we write

$$[\phi^{j'\mu'}]_{sc} = \sum_M B^{j'\mu'}_M \delta_{M,\mu'} [JM]^+_+$$

the weight (relative) of the state $[JM]^+_+$ in the mixture is

$$p(M) = \sum_{j'} |B^{j'M}_M|^2 = (2J+1)|c^+_J - 1|^2 \times \sum_{j'} \left| \sum_{l'} (2l'+1)^{\frac{1}{2}} \begin{pmatrix} J & l' & j' \\ -M & 0 & M \end{pmatrix} x^*_{l'j's} \right|^2. \quad (43)$$

(The characteristic energy dependence of the differential cross-section near resonance is contained in the resonance factor $|c^+_J - 1|^2$.)

We may now proceed to the calculation of the distribution of the emitted h particles by the same methods employed for the correlation calculation. The $[JM]^+_+$ state, by (37) is

$$[JM]^+_+ = \sum_{l'j's'} x^*_{l'j's'} [JMl'j's']_+.$$

(Note that whereas in the preceding we dealt with the index s—for the j and I sub-systems—we now deal with s' for the h, k sub-systems.) We concern ourselves with that part of this sum which refers to the h and k particles. By a calculation precisely paralleling that of section (3B) we have (corresponding to (23)) for the distribution of the h particles arising from the scattered waves $[JM]^+_+$

$$W_M(\theta) = \sum_{j'\mu'} \left| \sum_{l''} \bar{x}^*_{l''j's'} \sum_{m'} \begin{pmatrix} J & j' & l' \\ -M & \mu' & m' \end{pmatrix} P^{\mu'}_{M'} \right|^2.$$

The distribution resulting from the mixture of $[JM]^+_+$ waves is given by

$$W(\theta) = \sum p(M) W_M(\theta). \quad (44)$$

It is clear that the general theorems obtained for the correlation function hold also for the distribution function (44).

5. CONCLUDING REMARKS

The immediate results of this paper, insofar as they relate to correlation distribution functions, are not applicable to the cases of major interest at the present time, namely the γ-γ and β-γ correlations. We hope to generalize the development given above in the near future and to provide detailed forms for the correlation distributions most likely to prove of interest.

I wish to thank Professor Wigner for his many helpful suggestions in the course of this work.

STRESS ANALYSIS OF A HEMISPHERICAL PRESSURE VESSEL HEAD UNDER CONCENTRIC LINE LOADS

BY

I. MALKIN [1]

1. INTRODUCTION

The problem of stress distribution in spherical shells occurs not infrequently in the practice of the pressure vessel designer. Since the particular loading conditions encountered in actual design are not always of the kind treated in the literature, the demand arises for adequate discussion of certain special loading cases. The purpose of the present article is to work out a complete numerical solution for the case of loads, uniformly distributed along several concentric circles drawn on the sphere symmetrically with respect to the axis of the vessel. Such a detailed numerical solution gives a valuable theoretical illustration of the general subject of the stress analysis of the spherical shell, and at the same time it represents a step towards standardization of the solution for the case of the particular loading conditions indicated, which is, of course, of considerable importance for practical design.

The historical background of the axisymmetrical elastic problem of shells in general and of its solution is quite well known; a few remarks concerning the matter will be helpful, however, for a better understanding of the concluding section of this article.[2] For the case of the spherical shell of constant thickness the solution was given essentially by H. Reissner as early as 1912. By an ingenious choice of two fundamental variables he succeeded in reducing A. E. H. Love's mathematical expression of the problem to a system of two symmetrical differential equations of the second order. Rigorous methods of integration of this system have been developed by E. Meissner shortly afterwards, while O. Blumenthal's approximate method of integration was used by Reissner. A still simpler approximate method of integration was introduced by J. W. Geckeler. This latter method will be used in the present article. The question of accuracy of this simplified method will be discussed at the end of the analysis.

We conclude these introductory remarks by referring the reader, in the interest of space economy, to S. Timoshenko's "Theory of Plates

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[2] The reader desiring more historical information will find such, together with an extensive bibliography of the subject, in J. W. GECKELER's "Schalen," in "Handbuch der Physik," Vol. VI (Elasticity), Berlin, 1928, pp. 231–265; see also G. W. WATTS and W. R. BURROWS, "The Basic Elastic Theory of Vessel Heads Under Internal Pressure," *Transactions of the ASME*, Applied Mechanics, March, 1949, pp. 55–73. Some additional literature references will be found in Timoshenko's "Theory of Plates and Shells," New York, McGraw-Hill Book Co., 1940.

and Shells," 1940, pp. 467–475 and 389–394, for designations as well as for origin of the formulas, used below; numbers and letters in square brackets refer to equations in that book.

2. THE PROBLEM

The loads, carried by the hemispherical head, can be attached to it in various ways. The connection between the shell and the loads can be arranged for instance in such a manner as to nearly prevent rotation of the meridian curve of the spherical shell at the points of connection.

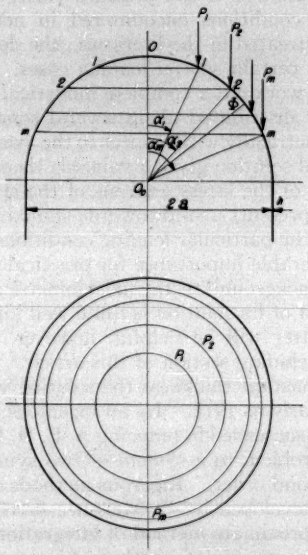

FIG. 1. Concentric line loads on hemispherical head.

In the following analysis, however, only the case will be considered that the loads are "pin jointed" to the shell. With this understanding we state our problem as follows:

The hemispherical head of a cylindrical pressure vessel is acted upon by loads uniformly distributed along the circles 1–1, 2–2, $\cdots$ (see Fig. 1), the load intensity being P_1, P_2, $\cdots$ per lineal inch of the respective circumferences. The vessel is under an internal pressure p psi. The wall thickness h of the vessel both in its spherical and cylindrical parts is everywhere the same. The stresses in the hemispherical head and at its connection with the cylindrical shell are to be determined.

Before turning to the solution we insert a remark. The weight of the spherical shell causes some stresses, too, but with the ratio of its radius to thickness of the order of magnitude to be considered below (see section 7) they still represent a minor factor only, which is, besides, treated in the literature, so that it can be omitted here from our further discussion.

3. FORMULAE FOR THE SPHERICAL SHELL

Referring to Fig. 2, the downward vertical force S_φ, transmitted

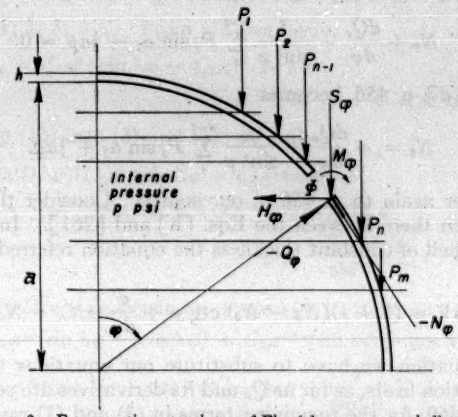

FIG. 2. Forces acting at point φ of Fig. 1 between two shell parts.

from the upper to the lower part of the shell at the point Φ, is given by[3]

$$S_\varphi = -Q_\varphi \cos\varphi - N_\varphi \sin\varphi = -\tfrac{1}{2}ap\sin\varphi + \frac{1}{\sin\varphi}\sum_1^{n-1} P_j \sin\alpha_j. \quad (1)$$

At the same point Φ there will be also a bending moment M_φ, and the two shell parts transmit there mutually a horizontal force H_φ, per lineal inch of the circumference, of the amount

$$H_\varphi = -Q_\varphi \sin\varphi + N_\varphi \cos\varphi \quad (2)$$

to each other. Equation 2 will be used in the statement of the boundary conditions of our problem.

Equation 1 can be written in the form

$$N_\varphi = -Q_\varphi \operatorname{ctg}\varphi - \frac{1}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j + \tfrac{1}{2}ap \quad (3)$$

[3] The same result is obtained by a consideration analogous to that given on p. 358 of Timoshenko's "Plates and Shells," with the *conventional* directions of the stress resultants acting on the separated upper part of the shell, as illustrated there by Fig. 139 and Eq. 209.

replacing Eq. [c], p. 455. Equation [258], p. 451, assumes now the form

$$N_\varphi a \sin\varphi + N_\vartheta a \sin\varphi + a\frac{d}{d\varphi}(Q_\varphi \sin\varphi) - a^2 p \sin\varphi = 0 \qquad (4)$$

from which

$$N_\varphi + N_\vartheta + \frac{dQ_\varphi}{d\varphi} + Q_\varphi \operatorname{ctg}\varphi - ap = 0. \qquad (5)$$

Combining (5) with (3), we get

$$N_\vartheta + \frac{dQ_\varphi}{d\varphi} - \frac{1}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j - \tfrac{1}{2}ap = 0 \qquad (6)$$

so that Eq. [d], p. 456, becomes

$$N_\vartheta = -\frac{dQ_\varphi}{d\varphi} + \frac{1}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j + \tfrac{1}{2}ap. \qquad (7)$$

Now we refer again to p. 456 of our source. Consider the equation, which is given there between the Eqs. [h] and [261]. In the case of a spherical shell of constant thickness the equation referred to assumes the form

$$EhV = (1+\nu)(N_\varphi - N_\vartheta)\operatorname{ctg}\varphi + \frac{d}{d\varphi}(\nu N_\varphi - N_\vartheta). \qquad (8)$$

Into this equation we have to substitute our equations (3) and (7). The substitution leads, as far as Q_φ and its derivatives are concerned, to Eq. [g_1], p. 469; for the remaining terms in (3) and (7) we have

$$N_{\varphi 0} - N_{\vartheta 0} = -\frac{2}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j \qquad (9)$$

$$\nu N_{\varphi 0} - N_{\vartheta 0} = -\tfrac{1}{2}(1-\nu)ap - \frac{1+\nu}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j \qquad (10)$$

and the substitution of (9) and (10) into (8) gives, if the sum $\sum P_j \sin\alpha_j$ is temporarily designated by J,

$$EhV_0 = -(1+\nu)\operatorname{ctg}\varphi\frac{2J}{\sin^2\varphi} + \frac{2(1+\nu)}{\sin^3\varphi}J\cos\varphi = 0.$$

Therefore, Eq. [g_1] remains unchanged. From p. 456, bottom, and p. 457, top, of our source we conclude, furthermore, that Eq. [262] remains unchanged as well, because our expressions (3) and (7) for N_φ and N_ϑ, respectively, are not involved. Thus [263_2], p. 457, remains unchanged, as well as Eq. [g_2], p. 469. Consequently, the system [h], p. 469, remains valid, and we have

$$Q'' = EhV \qquad \text{and} \qquad V'' = -(a^2/D)Q_\varphi,$$

where an accent designates differentiation with respect to φ. From the last two equations we easily derive

$$V'''' + 4\lambda^4 V = 0, \tag{11}$$

where the constant λ^4 is defined by [j], p. 469. In analogy to [k], p. 469, we get now

$$\left.\begin{aligned} V = {} & C_{1j}e^{\lambda\varphi}\cos\lambda\varphi + C_{2j}e^{\lambda\varphi}\sin\lambda\varphi \\ & + C_{3j}e^{-\lambda\varphi}\cos\lambda\varphi + C_{4j}e^{-\lambda\varphi}\sin d\varphi, \end{aligned}\right\} \tag{12}$$

where $j = 1; 2; 3; \cdots$. From (12) we derive

$$\left.\begin{aligned} (a^2/2\lambda^2 D)Q_\varphi = {} & C_{1j}e^{\lambda\varphi}\sin\lambda\varphi - C_{2j}e^{\lambda\varphi}\cos\lambda\varphi \\ & - C_{3j}e^{-\lambda\varphi}\sin\lambda\varphi + C_{4j}e^{-\lambda\varphi}\cos\lambda\varphi. \end{aligned}\right\} \tag{13}$$

Substituting (13) into (3) and (7), we find

$$\left.\begin{aligned} N_\varphi = {} & -(2\lambda^2 D/a^2)(C_{1j}e^{\lambda\varphi}\sin\lambda\varphi - C_{2j}e^{\lambda\varphi}\cos\lambda\varphi \\ & - C_{3j}e^{-\lambda\varphi}\sin\lambda\varphi + C_{4j}e^{-\lambda\varphi}\cos\lambda\varphi)\operatorname{ctg}\varphi \\ & + \tfrac{1}{2}ap - \frac{1}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j \end{aligned}\right\}. \tag{14}$$

$$\left.\begin{aligned} N_\theta = {} & -(2\lambda^2 D/a^2)[C_{1j}e^{\lambda\varphi}(\sin\lambda\varphi + \cos\lambda\varphi) \\ & + C_{2j}e^{\lambda\varphi}(\sin\lambda\varphi - \cos\lambda\varphi) + C_{3j}e^{-\lambda\varphi}(\sin\lambda\varphi - \cos\lambda\varphi) \\ & - C_{4j}e^{-\lambda\varphi}(\sin\lambda\varphi + \cos\lambda\varphi)] + \tfrac{1}{2}ap + \frac{1}{\sin^2\varphi}\sum_1^{n-1} P_j \sin\alpha_j \end{aligned}\right\}. \tag{15}$$

The bending moments are, in accordance with Eq. [q], p. 462, and Eq. [271], p. 470, given by

$$\left.\begin{aligned} M_\varphi = {} & -\frac{D}{a}V' = -\frac{D\lambda}{a}[C_{1j}e^{\lambda\varphi}(\cos\lambda\varphi - \sin\lambda\varphi) \\ & + C_{2j}e^{\lambda\varphi}(\sin\lambda\varphi + \cos\lambda\varphi) - C_{3j}e^{-\lambda\varphi}(\sin\lambda\varphi + \cos\lambda\varphi) \\ & - C_{4j}e^{-\lambda\varphi}(\sin\lambda\varphi - \cos\lambda\varphi)] \end{aligned}\right\}, \tag{16}$$

$$M_\theta = \nu M_\varphi. \tag{17}$$

According to [r], p. 462, in connection with our Eqs. 3 and 7,

$$\left.\begin{aligned} \delta = \frac{a\sin\varphi}{Eh}(N_\theta - \nu N_\varphi) = {} & -\frac{1}{2}\frac{a}{\lambda}[C_{1j}e^{\lambda\varphi}(\sin\lambda\varphi + \cos\lambda\varphi) \\ & + C_{2j}e^{\lambda\varphi}(\sin\lambda\varphi - \cos\lambda\varphi) + C_{3j}e^{-\lambda\varphi}(\sin\lambda\varphi - \cos\lambda\varphi) \\ & - C_{4j}e^{-\lambda\varphi}(\sin\lambda\varphi + \cos\lambda\varphi)] \\ & + \frac{(1+\nu)a}{Eh}\left(\sum_1^{n-1} P_j \sin\alpha_j\right)\frac{1}{\sin\varphi} + \frac{(1-\nu)a^2 p}{2Eh}\sin\varphi \end{aligned}\right\}. \tag{18}$$

4. FORMULAE FOR THE CYLINDRICAL SHELL

The system (19) to (24), given below, represents but a slight modification of the formulae to be found on pp. 389–391 of our source. The changes are due to two causes. The first is that the constant N_x is not zero in our equations, while the source omits N_x from consideration. The second is that the particular integral of Eq. [230], p. 392, is taken into account, while the source similarly omits this item again, since it is not needed in the discussions presented on those pages. Taking care of those two items in the derivations of pp. 391–393 of our source, the reader will easily verify the following set of equations, in which p = *internal* pressure and w = *inward* deflection in conjunction with other sign conventions implied in our Fig. 3:

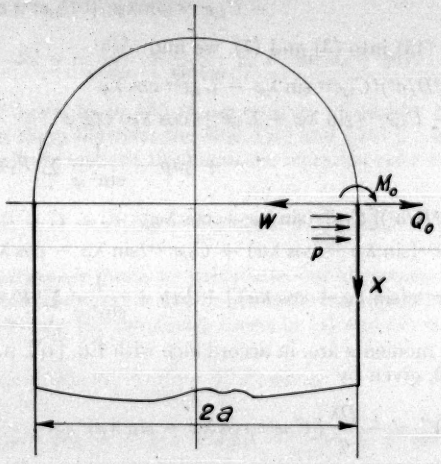

FIG. 3. Illustrating sign conventions for cylinder analysis.

$$w = \frac{e^{-\beta x}}{2\beta^3 D}\left[\beta M_0(\sin \beta x - \cos \beta x) - Q_0 \cos \beta x\right] + \frac{\nu a}{Eh} N_x - \frac{a^2 p}{Eh} \tag{19}$$

$$N_\phi = \nu N_x - \frac{Eh}{a} w \tag{20}$$

$$M_x = M_0 e^{-\beta x}(\cos \beta x + \sin \beta x) + \frac{Q_0}{\beta} e^{-\beta x} \sin \beta x \tag{21}$$

$$M_\phi = \nu M_x \tag{22}$$

$$Q_x = -2\beta M_0 e^{-\beta x} \sin \beta x + Q_0 e^{-\beta x}(\cos \beta x - \sin \beta x) \tag{23}$$

$$\frac{dw}{dx} = \frac{e^{-\beta x}}{2\beta^2 D}\left[2\beta M_0 \cos \beta x + Q_0(\cos \beta x + \sin \beta x)\right]. \tag{24}$$

5. THE AVAILABLE CONSTANTS AND THE BOUNDARY CONDITIONS

The unknowns of our problem are the coefficients C_{1j}, C_{2j}, C_{3j}, C_{4j} ($j = 1$ to $m + 1$, if m = number of the loading circles) for the spherical part of the shell and the constants M_0, Q_0, N_x for the cylindrical part, or $4(m + 1) + 3 = 4m + 7$ unknowns altogether. The conditions available for determination of these $4m + 7$ unknowns are as follows. At the top of the spherical shell ($\varphi = 0$) we must have $Q_\varphi = 0$ and $V = 0$ (these two conditions are equivalent to putting $C_{3j} = 0$, $C_{4j} = 0$, as a detailed consideration shows, which must be omitted here). At each of the m loading circles the radial displacement δ, the bending moment M_φ and the rotation V must be continuous; these are $3m$ conditions, so that thus far we have $3m + 2$ conditions. A further set of relations is obtained in the following manner. From our Eqs. 1 and 2 we derive the formula

$$-Q_\varphi = -\tfrac{1}{4}ap \sin 2\varphi + \operatorname{ctg} \varphi \sum_1^{n-1} P_j \sin \alpha_j + H_\varphi \sin \varphi. \tag{25}$$

At each of the loading circles $n = 1; 2; 3; \cdots$ Eq. 25 assumes the form

$$-Q_\varphi = -\tfrac{1}{4}ap \sin 2\alpha_n + \operatorname{ctg} \alpha_n \sum P_j \sin \alpha_j + H_\varphi \sin \alpha_n, \tag{26}$$

where the sum $\sum P_j \sin \alpha_j$ can signify any of the two expressions

$$\sum_1^{n-1} P_j \sin \alpha_j \qquad \text{and} \qquad \sum_1^{n} P_j \sin \alpha_j \tag{27}$$

depending on whether the point n is being considered the lower boundary of part $n - 1$, n or the upper boundary of the part n, $n + 1$. At the point n we have, according to (26) and (27), the two relations

$$\left.\begin{aligned} -Q_{\varphi n}^- &= -\tfrac{1}{4}ap \sin 2\alpha_n + \operatorname{ctg} \alpha_n \sum_1^{n-1} P_j \sin \alpha_j + H_\varphi \sin \alpha_n \\ -Q_{\varphi n}^+ &= -\tfrac{1}{4}ap \sin 2\alpha_n + \operatorname{ctg} \alpha_n \sum_1^{n} P_j \sin \alpha_j + H_\varphi \sin \alpha_n \end{aligned}\right\}. \tag{28}$$

Since H_φ must be a continuous function of φ in the entire interval $0 \leqslant \varphi \leqslant \frac{1}{2}\pi$, the system (28) permits the conclusion

$$Q_{\varphi n}^+ - Q_{\varphi n}^- = -P_n \cos \alpha_n. \tag{29}$$

With the aid of (13) the relation (29) can be written, with the index j used instead of the index n, in the form

$$\left.\begin{aligned} &(C_{1,j+1} - C_{1j})e^{\lambda\alpha_j} \sin \lambda\alpha_j \\ &\quad - (C_{2,j+1} - C_{2j})e^{\lambda\alpha_j} \cos \lambda\alpha_j - (C_{3,j+1} - C_{3j})e^{-\lambda\alpha_j} \sin \lambda\alpha_j \\ &\quad + (C_{4,j+1} - C_{4j})e^{-\lambda\alpha_j} \cos \lambda\alpha_j = -\frac{a^2}{2\lambda^2 D} P_j \cos \alpha_j \end{aligned}\right\}. \tag{30}$$

This relation applies to each of the m loading circles of our problem, which adds m new conditions, so that with the preceding $3m + 2$ conditions we have now $4m + 2$ conditions. Finally, at the connection of sphere and cylinder the following relations must be fulfilled:

1. continuity of radial displacement,
2. continuity of rotation,
3. continuity of bending moment,
4. continuity of shear force, and
5. continuity of longitudinal force (N_x, N_φ).

Thus we have altogether $4m + 7$ conditions for the $4m + 7$ unknowns of our problem.

We turn now to the explicit formulation and solution of the condition equations just indicated.

6. THE CONDITION EQUATIONS AND THEIR SOLUTION

Introducing the designations

$$\left.\begin{aligned} (C_{1,j+1} - C_{1j})e^{\lambda\alpha_j} &= x_j; & (C_{2,j+1} - C_{2j})e^{\lambda\alpha_j} &= y_j \\ (C_{3,j+1} - C_{3j})e^{-\lambda\alpha_j} &= z_j; & (C_{4,j+1} - C_{4j})e^{-\lambda\alpha_j} &= t_j \end{aligned}\right\} \tag{31}$$

$$\sin\lambda\alpha_j = s \qquad \cos\lambda\alpha_j = c \tag{32}$$

$$\frac{2(1+\nu)\lambda}{Eh\sin\alpha_j} P_j = Q_j; \qquad -\frac{2\lambda^2}{Eh} P_j \cos\alpha_j = R_j$$

the condition equations for the constants of our problem can be written now with the aid of the expressions (12), (13), (16), (18), (29), and in the order, in which they have been pointed out above, as follows:

$$-C_{21} + C_{41} = 0, \qquad C_{11} + C_{31} = 0, \tag{34}$$

$$(s+c)x_j + (s-c)y_j + (s-c)z_j - (s+c)t_j = Q_j, \tag{35}$$

$$(c-s)x_j + (s+c)y_j - (s+c)z_j - (s-c)t_j = 0, \tag{36}$$

$$cx_j + sy_j + cz_j + st_j = 0, \tag{37}$$

$$sx_j - cy_j - sz_j + ct_j = R_j. \tag{38}$$

The solution of the system (35) to (38) is, as easily verified by substitution,

$$x_j = (C_{1,j+1} - C_{1j})e^{\lambda\alpha_j} = \tfrac{1}{4}Q_j(\sin\lambda\alpha_j + \cos\lambda\alpha_j) + \tfrac{1}{2}R_j\sin\lambda\alpha_j, \tag{39}$$

$$y_j = (C_{2,j+1} - C_{2j})e^{\lambda\alpha_j} = \tfrac{1}{4}Q_j(\sin\lambda\alpha_j - \cos\lambda\alpha_j) - \tfrac{1}{2}R_j\cos\lambda\alpha_j, \tag{40}$$

$$z_j = (C_{3,j+1} - C_{3j})e^{-\lambda\alpha_j} = \tfrac{1}{4}Q_j(\sin\lambda\alpha_j - \cos\lambda\alpha_j) - \tfrac{1}{2}R_j\sin\lambda\alpha_j, \tag{41}$$

$$t_j = (C_{4,j+1} - C_{4j})e^{-\lambda\alpha_j} = -\tfrac{1}{4}Q_j(\sin\lambda\alpha_j + \cos\lambda\alpha_j) + \tfrac{1}{2}R_j\cos\lambda\alpha_j. \tag{42}$$

The right hand expressions permit the computation of the constants

x_j, y_j, z_j, t_j for $j = 1; 2; 3; \cdots$. Having computed these constants, we arrive at the system

$$C_{1,j+1} = C_{1j} + x_j e^{-\lambda\alpha_j}, \tag{43}$$

$$C_{2,j+1} = C_{2j} + y_j e^{-\lambda\alpha_j}, \tag{44}$$

$$C_{3,j+1} = C_{3j} + z_j e^{\lambda\alpha_j}, \tag{45}$$

$$C_{4,j+1} = C_{4j} + t_j e^{\lambda\alpha_j}. \tag{46}$$

Starting from $j = 1$ and using the relations (34), we obtain from the system (43) to (46) expressions for the constants C_{12}, C_{22}, C_{32}, C_{42} in terms of C_{11} and C_{21}; substituting then $j = 2$ into (43) to (46), we find expressions for the constants C_{13}, C_{23}, C_{33}, C_{43} in terms of C_{11} and C_{21}, and so forth. In this way all C constants are reduced to the two constants C_{11}, C_{21}, namely,

$$C_{1,k+1} = C_{11} + \sum_1^k x_j e^{-\lambda\alpha_j}, \tag{43a}$$

$$C_{2,k+1} = C_{21} + \sum_1^k y_j e^{-\lambda\alpha_j}, \tag{44a}$$

$$C_{3,k+1} = -C_{11} + \sum_1^k z_j e^{\lambda\alpha_j}, \tag{45a}$$

$$C_{4,k+1} = C_{21} + \sum_1^k t_j e^{\lambda\alpha_j}, \tag{46a}$$

$$(k = 1; 2; 3; \cdots; m).$$

For the two unknowns C_{11} and C_{21} and for those of the cylindrical part we use the following relations.

Applying the continuity condition 5 (see above) to Eq. 14 with $\varphi = \frac{1}{2}\pi$, we find

$$N_x = \tfrac{1}{2}ap - \sum_1^m P_j \sin\alpha_j. \tag{47}$$

Now we introduce the notations

$$\left.\begin{aligned} C_{1,m+1}e^{\frac{1}{2}\lambda\pi} &= c_{1,m+1}; & C_{2,m+1}e^{\frac{1}{2}\lambda\pi} &= c_{2,m+1};\\ C_{3,m+1}e^{-\frac{1}{2}\lambda\pi} &= c_{3,m+1}; & C_{4,m+1}e^{-\frac{1}{2}\lambda\pi} &= c_{4,m+1} \end{aligned}\right\} \tag{48}$$

$$\sin\tfrac{1}{2}\lambda\pi = s_0, \qquad \cos\tfrac{1}{2}\lambda\pi = c_0. \tag{32a}$$

With the aid of (18) and (19) in connection with (47), and with $\alpha_{m+1} = \frac{1}{2}\pi$, the continuity condition 1 yields the first equation of the system (49) given below. In a similar manner we obtain from our continuity condition 2, applied to (12) and (24), the second equation of the system (49). The continuity conditions 3 and 4 give us analogously the last two equations of the system (49), and so we have

$$\left.\begin{aligned} c_{1,m+1}(s_0+c_0)+c_{2,m+1}(s_0-c_0)+c_{3,m+1}(s_0-c_0)-c_{4,m+1}(s_0+c_0) &= S_1\\ c_{1,m+1}c_0 \quad +c_{2,m+1}s_0 \quad +c_{3,m+1}c_0 \quad +c_{4,m+1}s_0 &= S_2\\ -c_{1,m+1}(s_0-c_0)+c_{2,m+1}(s_0+c_0)-c_{3,m+1}(s_0+c_0)-c_{4,m+1}(s_0-c_0) &= S_3\\ c_{1,m+1}s_0 \quad -c_{2,m+1}c_0 \quad -c_{3,m+1}s_0 \quad +c_{4,m+1}c_0 &= S_4 \end{aligned}\right\}, \tag{49}$$

where

$$S_1 = -\frac{2\lambda}{Eah}\tfrac{1}{2}a^2p + 2\lambda(\lambda M_0 + aQ_0) - a\sum_1^m P_j \sin\alpha_j, \qquad (50_1)$$

$$S_2 = \frac{2\lambda}{Eah}(2\lambda^2 M_0 + \lambda a Q_0); \qquad S_3 = -\frac{4\lambda^3}{Eah}M_0; \qquad S_4 = \frac{2\lambda^2}{Eh}Q_0. \qquad (50_2)$$

With the abbreviations

$$\lambda : 2Eh = \mu; \qquad \sin\tfrac{1}{2}\lambda\pi \pm \cos\tfrac{1}{2}\lambda\pi = \frac{\sigma^+}{\sigma^-}; \qquad 4\lambda^3 : Eah = \Gamma \qquad (51)$$

the solution of (49) can be written in the form

$$c_{1,m+1} = \mu(\sum_1^m P_j \sin\alpha_j - \tfrac{1}{2}ap)\sigma^+ \qquad (52)$$

$$c_{2,m+1} = \mu(\sum_1^m P_j \sin\alpha_j - \tfrac{1}{2}ap)\sigma^- \qquad (53)$$

$$c_{3,m+1} = (\Gamma\cos\tfrac{1}{2}\lambda\pi)M_0 + \mu(4\lambda Q_0 - \sum_1^m P_j \sin\alpha_j + \tfrac{1}{2}ap)\sigma^- \qquad (54)$$

$$c_{4,m+1} = (\Gamma\sin\tfrac{1}{2}\lambda\pi)M_0 + \mu(4\lambda Q_0 - \sum_1^m P_j \sin\alpha_j + \tfrac{1}{2}ap)\sigma^+. \qquad (55)$$

Substituting $k = m$ into (43a), multiplying (52) by $e^{-\frac{1}{2}\lambda\pi}$ and equating the two results, we find at once the constant C_{11}. In the same manner we find the constant C_{21} from (44a) and (53). Knowing C_{11} and C_{21}, we obtain from (45a) and (46a) the constants $C_{3,m+1}$ and $C_{4,m+1}$. Introducing the results into (54) and (55), we have two linear equations for the last two unknowns M_0 and Q_0. Solving these equations, we have all constants, and the problem is completely solved.

The solution thus developed will be illustrated now by a numerical example.

7. NUMERICAL EXAMPLE

The numerical computations must be carried out with considerable accuracy in our problem. An electric calculating machine and 6 and 7 places numerical tables have been used in the work reproduced below.

We consider the case characterized by

$a = 334''$; $h = 1''$; $p = 15$ psi; $\alpha_1 = 16°\,52'$; $\alpha_2 = 30°\,32'$; $\alpha_3 = 33°\,56'$; $\alpha_4 = 43°\,12'$; $\alpha_5 = 90°\,00'$; Temperature 650° F. $P_1 = 135$ lb; $P_2 = 83$ lb; $P_3 = 100$ lb; $P_4 = 100$ lb.

The temperature influences not only the amount of the allowable stresses, but it determines also the modulus of Elasticity

$$E = 25.5 \times 10^6.$$

According to [j], p. 469, λ becomes equal to 23.49. For convenience of computation we choose

$$\lambda = 23.50. \tag{56}$$

Carrying out the computations indicated in the preceding sections we obtain the stress resultants, stress moment resultants and stresses given in Table I.

TABLE I.

Sect.	Angle	Q_φ lb./in.	N_φ lb./in.	N_θ lb./in.	M_φ lb. in/in.	M_θ lb. in/in.	σ_φ psi.
0–1	0	0	2,500	2,500	0	0	2,500
	α_1	58	2,315	1,290	460	138	5,080
1–2	α_1	−71	2,275	1,150	460	138	5,040
	α_2	36	2,295	1,650	208	62	3,540
2–3	α_2	−36	2,250	1,590	208	62	3,500
	α_3	37	2,300	1,685	235	70	3,710
3–4	α_3	−46	2,135	1,630	235	70	3,540
	α_4	34	2,175	2,070	261	78	3,740
4–5	α_4	−38	2,110	2,030	261	78	3,760
	α_5	−24.5	2,310	3,860	0	0	2,310
Cylinder		−24.5	2,310	3,860	0	0	2,310

The bending moment M_0 at the juncture of cylinder and sphere is zero (see, however, below), but the shear force Q_0 produces some bending in the cylinder; this bending can be easily computed as follows.[4] The bending moment due to Q_0 is, with the designations of the source

$$M_x = -\frac{Q_\varphi a}{\lambda}\zeta(\beta x).$$

The maximum of M_x appears at

$$\beta x = \frac{\pi}{4}; \qquad x = \pi a : 4\lambda = 334\pi : (4 \times 23.5) = \sim 11''$$

and with $\zeta(\frac{1}{4}\pi) = 0.32$

$$M_{x\max} = (24.5 \times 334 \times 0.32) : 23.5 = 112 \text{ in lb/in.}$$

8. DISCUSSION OF THE RESULTS

The attentive reader will dwell to some length upon the results as expressed by comparison of the longitudinal stresses $\sigma_{\varphi 1}$ due to the forces N_φ with the longitudinal stresses $\sigma_{\varphi 2}$ due to the moments M_φ:

$$\sigma_{\varphi 1} = N_\varphi : h = N_\varphi : 1 = N_\varphi \text{ psi}; \qquad \sigma_{\varphi 2} = 6M_\varphi : h^2 = 6M_\varphi \text{ psi}.$$

[4] See S. TIMOSHENKO, "Plates and Shells," 1940, pp. 408–409, in connection with p. 392 and 469 (definition of β and λ, respectively).

While the forces N_φ are predominantly determined by the pressure $p = 15$ psi. {Eq. (3)}, the bending moments can be produced only by the loads P_j, because the discontinuity effects, represented by $M_0 = 0$ and $Q_0 = -24.5$ lb/in. cannot produce those bending moments in such considerable distance from the discontinuity spot ($\varphi = \frac{1}{2}\pi$). It is, of course, interesting to see how this mutual relationship of the influences of pressure and line loads expresses itself mathematically. The bending moments M_φ are determined by the constants C_{1j} to C_{4j}. These constants are given by the form (43a) to (46a). The sums $\sum$ occurring in this system of formulas are determined by the loads P_j only according to (39) to (42). Now to the constants C_{11} and C_{21} occurring in (43a) to (46a). By virtue of (52) to (55) in connection with the remark immediately following that system of formulas the determination of the constants C_{11} and C_{31} is linked to that of the constants C_{15}, C_{25}, C_{35}, C_{45}, which are influenced by the pressure p {Eq. (52) to (55)}; this influence is, however, the quicker overshadowed by that of the loads P_j {Eq. (43a) to (46a) in connection with (39) to (42)}, the larger the latter are. The influence of the loads P_j, as evident from Table I, is all the more remarkable that, while the resulting amount of the total pressure force is

$$\pi a^2 p = \pi \times 334 \times 15 = 5.25 \times 10^6 \text{ lb.}$$

the resulting total load due to the line forces P_j is

$$2\pi a \sum_1^4 P_j \sin \alpha_j = 2\pi \times 334 \times 205 = 430{,}000 \text{ lb.}$$

so that the resulting line load is only about 8 per cent of the pressure load, and still we have $\sigma_{\varphi 2} > \sigma_{\varphi 1}$ at $\varphi = \alpha_1$. Naturally, the bending moments decrease very rapidly as we move away from the loading circles.

9. NOTES ON ACCURACY OF THE SOLUTION

As briefly mentioned already in the Introduction, the computing procedure used in the preceding analysis is based upon an *approximate* solution of the differential equations of the problem of the symmetrically loaded spherical shell of constant thickness. The question of accuracy of the approximate methods in this problem has been discussed on several occasions. A valuable numerical illustration to this question has been worked out by M. Hetenyi and reproduced in Timoshenko's "Plates and Shells."[5] Geckeler's approximate method of integration, used in the present article, is designated by Timoshenko as "Approximation I," while the procedure used by Hetenyi and based upon O. Blumenthal's approximate method, is designated there as "Approximation II." The diagrams given in that example show the results obtained from the *exact integration* as well and permit, therefore, a good judgment about accuracy of the approximate methods of solution. We see from those

[5] See M. HETENYI, *Publ. Intern. Assoc. Bridge Struct. Eng.*, Vol. 5, p. 173, 1938; S. TIMOSHENKO, "Plates and Shells," pp. 473–475, particularly Figs. 186 and 187.

graphs that "Approximation II" practically almost coincides with the accurate solution, while "Approximation I" is somewhat less satisfactory. Taking, however, into consideration that, while the ratio a/h is only 30 in that example, it is more than ten times as large in our preceding analysis, and that the approximate methods are the more accurate the larger that ratio, it is plausible to conclude that the "Approximation I" used in our above computations will be satisfactory for practical purposes.

A similar example is given by J. W. Geckeler.[6] His diagram shows the rotation V as determined by accurate integration and by "Approximation I" for a ratio a/h of about 600. The two solutions agree with each other very satisfactorily notwithstanding the unfavorable condition that the opening angle α of the shell is only 35° (the same angle as in Hetenyi's example).

The newest and most systematic approach to the subject treated here, with particular regard to determination of the so-called discontinuity stresses in pressure vessels at the juncture of the cylindrical part with the vessel head finds its expression in the paper of G. W. Watts and W. R. Burrows, referred to in the Introduction. The authors discuss vessel heads of various forms, including the hemispherical heads. They arrive by means of matrices at a very concise formulation of the system of operations necessary in the computation of the stress and deformation distribution at and beyond the juncture. In order to avoid sources of possibly non-negligible inaccuracies of any kind whatever they use only Meissner's exact methods of integrating Love's differential equations, see Introduction. A considerable amount of work will be necessary to carry out the program thus indicated; the work is now in progress.[7]

Without anticipating the results of this work for the case of a hemispherical head we shall attempt an amplification of our preceding analysis as far as the discontinuity stresses at the juncture of cylinder and hemisphere are concerned.

Preliminarily and fundamentally it must be emphasized that the use of Meissner's exact method of integration by means of the hypergeometric series is *ordinarily* out of question in the daily practice of the designing engineer because of the time factor. The series just mentioned converge very slowly and the convergence is the worse the larger the ratio a/h. In Hetenyi's example, where $a/h = 30$, it was necessary to use ten terms of the series to obtain sufficient accuracy; in Geckeler's example, where $a/h = 600$, not less than 35 terms had to be taken in each of the series involved, and the terms grew first to roughly one hundredfold amounts of the sums toward which the series ultimately converged. Still another example of this kind is given by J. E.

[6] J. W. GECKELER, *loc. cit.*, pp. 250–251, particularly Fig. 66.

[7] See G. W. WATTS and W. R. BURROWS, *loc. cit.*, p. 55, footnote 1.

Erkstroem,[8] who had to use not less than 18 terms in a case where $a/h = 62.5$. The difficulties are greatly multiplied when the shell has two boundaries which means the appearance of *four* integrals. All of these examples and considerations indicate clearly that while it is very desirable to give the particular problem in question a thorough and rigorous study, this can be done, once and for all, only in an extensive ambitious program of the kind just announced, while we will have here to limit ourselves to a modest and moderate task.

Turning specifically to the discontinuity stresses at the juncture of cylinder and sphere, we shall apply the following check to our preceding results. Since the juncture is far away from the loading circles, we can apply to the hemispherical head at the juncture the set of formulas [m], [269], [270], [271], [272], p. 470, representing the above "Approximation I," or the set [275], [276], p. 473 (in connection with the formulas for k_1 and k_2 on p. 474), representing the "Approximation II"; in both cases the influence of the pressure p and the line loads P_j must be introduced additionally, of course. Substituting into these two systems the value $\psi = 0$, we obtain the non-trivial result that both sets lead to *the same* system of formulas, namely[9]

$$\left.\begin{aligned} Q_\varphi &= C\sin\gamma; \quad N_\varphi = \tfrac{1}{2}ap - \sum_1^m P_j \sin\alpha_j; \\ N_\theta &= \lambda C(\cos\gamma - \sin\gamma) + \tfrac{1}{2}ap + \sum_1^m P_j \sin\alpha_j \\ V &= -\frac{2\lambda^2}{Eh} C\cos\gamma; \quad M_\varphi = \frac{1}{2}\frac{a}{\lambda} C(\sin\gamma + \cos\gamma); \\ M_\theta &= \frac{1}{2}\frac{a\nu}{\lambda} C(\sin\gamma + \cos\gamma) \\ Eh\delta &= -a\lambda C(\sin\gamma - \cos\gamma) \\ &\quad + (1+\nu)a\sum_1^m P_j \sin\alpha_j + \tfrac{1}{2}(1-\nu)a^2 p \end{aligned}\right\} \quad (57)$$

The coincidence is not trivial because the two identical systems arise from integration of two non-identical systems of differential equations. It is only true that at the particular point $\varphi = 90°$, or $\psi = 0$, the two systems of differential equations to be integrated become closely similar to each other, but this does not mean that integration and substitution of $\psi = 0$ must produce closely similar results (the process of solution involves integration and *differentiations*, and the derivatives of approximate functions are not necessarily satisfactory approximations of the accurate derivatives of the accurate functions). Since, however, those two operations actually do lead to identical results in both systems, there is some reason to believe that even the strictly accurate solution

[8] J. E. ERKSTROEM, *Ing. Vetensk. Akad.*, Vol. 121, Stockholm, 1933; quoted according to S. TIMOSHENKO, "Theory of Plates and Shells," 1940, p. 467.

[9] The factor λ is missing in the formula for N_θ in [276].

of the problem will not yield anything else but the coinciding results obtained from "Approximation I" and "Approximation II." This is, of course, only a plausible consideration and no proof. It is to be hoped that the research work mentioned above will clear up the situation.

The system (19) to (24) assumes for $x = 0$, with $\beta = \lambda/a$ and $D = Eh^3/12(1 - \nu^2)$, and by virtue of [j], p. 469, the form

$$\left.\begin{aligned} Ehw &= -2(\lambda^2 M_0 + a\lambda Q_0) + \nu a N_x - a^2 p; \\ N_\phi &= 2\left(\frac{\lambda^2}{a^2} M_0 + \lambda Q_0\right) + ap \\ M_x = M_0; \quad M_\varphi &= \nu M_0; \quad Q_x = Q_0; \\ dw/dx &= \frac{2\lambda^2}{Eh}\left(2\frac{\lambda}{a} M_0 + Q_0\right) \end{aligned}\right\} \quad (58)$$

Equating the first, second, fourth, fifth and seventh of the expressions (57) to the corresponding expressions (58) we finally find

$$M_0 = 0, \qquad Q_0 = -\frac{1}{4\lambda}\left(\tfrac{1}{2}ap - \sum_1^m P_j \sin \alpha_j\right), \qquad \sin \gamma = -\cos \gamma.$$

Substituting for a, p, λ and $\sum P_j \sin \alpha_j$ the numerical values given above we find

$$Q_0 = -24.5 \text{ lb./lin. in.}$$

as before. Substituting, furthermore, $\sin \gamma = -\cos \gamma$ into the expression for N_θ in (57) and comparing the result with N_φ in (58) we find even[10]

$$N_\theta = N_\phi, \qquad \text{when} \qquad \psi = 0$$

as before, and particularly $N_\theta = N_\phi = 3{,}860$ lb./lin. in. as before.

So we see that at the juncture the two approximations I and II yield the same results as our preceding calculations. Particularly noteworthy is that the vanishing of the bending moment at the juncture is a characteristic feature of the approximate methods,[11] and this is, therefore, a point where the approximate methods and the accurate solution should be compared with each other once for all. The results obtained above are those which can be obtained as far as the approximate methods go.

Acknowledgment

The author uses with pleasure the opportunity of expressing his gratitude to Messrs. Martin Frisch and A. H. Egsieker of the Foster Wheeler Corporation in New York City for their kind permission to publish the above analysis. He wishes also to express his thanks to Mr. Jacob Cooper of the same organization for his careful check of the numerical work in Section 7.

[10] Cf. G. W. WATTS and W. R. BURROWS, *loc. cit.*, p. 59.

[11] See S. TIMOSHENKO, "Plates and Shells," pp. 407–408.

Freeze Drying.—You can dry frozen materials such as blood plasma from 70 to 90 per cent faster by feeding them penetrating "hot-shots" of electricity than you can by merely conducting heat to them, a University of Wisconsin student and his professor have shown in research studies they conducted in chemical engineering.

They found that freeze drying with radiant energy is more rapid than with conduction heating because of the penetration of radiation into the product. They found out, for example, that the freeze-drying capacity of an organic dye was increased by 74 per cent by virtue of the penetrating effect of radiant energy. The advantages of the reduction in drying time would be reflected in lower equipment costs and reduced operating costs for the freeze-drying process, they explained.

The Wisconsin experimenters who made the findings are W. H. Zamzow, and W. R. Marshall, Jr. The work was done under the Wisconsin Engineering Experiment station and was partially supported by the Wisconsin Alumni Research foundation. It was reported at a meeting of the American Institute of Chemical Engineers.

Medical products to which this freeze-drying process has been applied include blood plasma, blood fractions, streptomycin, albumin, vaccines, and hormones. Prior to the development of freeze drying, these products could not be obtained in dry form with the same high level of potency.

Neither freeze drying by radiant heat transfer nor by conduction heat transfer are new processes, but widespread industrial application of such drying methods on medical and food products occurred only during and since World War II, they reported.

Since freeze drying has come into greater industrial use, there have been questions in the minds of scientists and engineers as to the comparative effectiveness of freeze drying by conduction heating as against freeze drying with penetrating radiant energy.

In freeze drying, a material is dried in vacuum in its frozen state by reducing its water content as ice rather than by evaporating it as a liquid.

In freeze drying by conduction heating, the heat is conducted to the frozen material through a solid retaining medium heated by circulating liquids or gases. In freeze drying with radiant energy, heat penetrates in suitable wave bands right through the frozen product to reduce it to its lighter and less bulky state but still preserve its value and quality.

The Wisconsin scientists reported that in commercial practice the time of freeze drying streptomycin was cut from 48 hr. by conduction heating to 12 hr. by radiant heating, blood plasma from 48 hr. to 14 hr., albumin from 48 to 3 hr., hormones from 24 to 2.4 hr., blood fractions from 84 to 12, and vaccines from 24 to 3 hr.

For some of these materials, reduction in drying time under radiant freeze drying may have been responsible for a higher level potency of the finished dried product, which was not obtainable by conduction freeze drying, the Wisconsin engineers reported.

PAUCITY OF QUANTA RENDERING A SILVER HALIDE GRAIN DEVELOPABLE

UNIQUENESS OF QUANTIC REPRESENTATION OF A SIMPLE [1] SENSITOMETRIC CURVE

BY

LUDWIK SILBERSTEIN [2]

In the course of the last twenty-five years, numerous *simple* characteristic (sensitometric) curves observed on a great variety of photographic emulsions were found by the present writer to be very closely represented by a single r-quantic term

$$\frac{D(y)}{D_m} = \frac{y^r(r+1+y)}{(1+y)^{r+1}}, \tag{1}$$

where y is the exposure variable $a\epsilon n$* and r the number of quanta necessary and sufficient for making a grain developable, in most cases equal to 2 or 3. The expression (1), derived and utilized previously on several occasions, is based on the elementary principles of the Quantum Theory of Exposure and upon the schematic (but demonstrably satisfactory) assumption that the emulsion (if not homogeneous) has an exponential size-frequency distribution,

$$f(a) = e^{-a/\bar{a}} : \bar{a},^{**}$$

and that all grains of the emulsion call for *the same number* r of quanta and have *the same* intrinsic sensitivity ϵ.

For a *uniform* or homogeneous emulsion (or a narrow size-class of grains), consisting, that is, of N grains all of size a and sensitivity ϵ, the number k of grains made developable by an exposure $y = \epsilon an$ is well represented by a single r-quantic term

$$k(y) = N\left\{1 - e^{-y}\sum_{\kappa=1}^{r-1}\frac{y^\kappa}{\kappa!}\right\}, \tag{2}$$

again with a low value of the quantum number, $r = 2$ or 3 for visible light and $r = 1$ for all X-ray exposures. The formula (1) is only (2) itself integrated over all sizes.

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[1] The photographic density as a function of exposure of a simple sensitometric curve can be expressed by a single quantic expression.

[2] Deceased; formerly Scientific Consultant, Rochester, N. Y.

* n = number of quanta incident, per unit area, $\bar{a}$ = average grain size (projected area), ϵ the "intrinsic sensitivity," a pure number, generally of the order 10^{-6} to 10^{-3}.

** $f(a)da$ being the fraction of all grains present which have a size a to $a + da$.

The persistent feature of all our trials was that, in either case (microphotographic counts treated by (2) and macroscopic density measurements treated by (1)), the number r called for by the observations amounted to a very few units, rarely exceeding 2 or 3.

It is the purpose of the present writing to show that the small r-values of *simple* characteristic curves are not due to the circumstance that we have attributed equal sensitivities ϵ to all grains present and that, if they are allowed a whole range of ϵ-values, artfully distributed, the experimental facts will drive us to huge values of the number r, nay, to as high values of r as we please, even though r be the same for all grains. Neither the dispersity of r's nor the dispersity of ϵ's among the grains can raise the actually required few quanta (required for developability) to a huge number (r) of quanta. More than this, we shall see that it can be easily proved if an observed curve, sensitometric or microphotographic, can at all be covered by a quantic expression, such as (1) or (2), with a *certain* value of r, it cannot be represented by a single quantic term or by a superposition of quantic terms with any other value of r whatever. In other words, a quantic representation of a given curve (if at all possible) is *unique*. A proof of such "uniqueness" will, of course, settle the whole question. For since we have represented closely many observed curves by quantic formulas with very low r-values, none of these curves can be represented quantically with any other r or $\bar{r}$-values, neither by the artifice of an ϵ-range nor that of an r-range.

Let us first consider the case of microphotographic grain counts and then that of the (integrated) macroscopic density-exposure curves, or as they may be briefly referred to, the case of a *uniform* emulsion and that of an "exponential" emulsion. We shall discuss first the scheme of an r-range and then that of an ϵ-range.

I. UNIFORM EMULSION

If each of the N grains calls for *the same* number r of quanta (to be made developable), the proportionate number of grains made developable by an exposure $y = \epsilon a n$ is, as in (2),

$$\frac{k(y)}{N} = 1 - e^{-y} \sum_{i=1}^{r-1} \frac{y^i}{i!}. \qquad (a)$$

On the other hand, if different grains call for different numbers, say s, of quanta, let $N\phi(s)$ be the number of grains calling for s quanta, where $\phi(s)$ is some arithmetical function of s, defined in some way or other for $s = 1, 2, 3, \cdots \infty$. The form of the function $\phi(s)$ will be left arbitrary, restricted only by the obvious condition

$$\sum_{1}^{\infty} \phi(s) = 1.$$

Then the proportionate number of grains made developable by an exposure $y = \epsilon an$ (where ϵ is common to all grains) will be

$$\frac{K(y)}{N} = 1 - e^{-y} \sum_{s=1}^{\infty} \phi(s) \sum_{i=1}^{s-1} \frac{y^i}{i!}. \qquad (b)$$

The *mean* quantum number will, in this case, be $\bar{r} = \sum_{s=1}^{\infty} \phi(s)s$.

Suppose now that an observed curve k, y has been represented by our formula (a) with some fixed r, such as 2 or 3. Can the same curve be represented by the formula (b) with a properly chosen function $\phi(s)$, leading to an $\bar{r} = \sum s\phi(s)$ different from the previous r? The answer is in the negative.

The simplest and shortest way to see this is as follows:

If K is to coincide with k for all exposures y, their derivatives with respect to y must also be identical, $K'(y) = k'(y)$, for all y. Now, by (a),

$$\frac{k'y}{N} = \frac{y^{r-1}}{(r-1)!} e^{-y}, \qquad (a')$$

and similarly for $K'(y)$, by (b). Thus

$$\frac{y^{r-1}}{(r-1)!} = \sum_{s=1}^{\infty} \phi(s) \frac{y^{s-1}}{(s-1)!}, \qquad (c)$$

and this equation must hold for all y. But, if so, then the coefficients of any power of y on both sides must be equal. Consequently $\phi(r) = 1$ and, for all $s \neq r$, $\phi(s) = 0$, which proves our proposition: a curve expressible by a single r-quantic term cannot be represented by any superposition of s-quantic terms, no matter how the numbers s are distributed among the N grains. In other words, the representation (a) is *unique*.

We have, so far, considered and ruled out the possibilities presumably afforded by a range of quantum numbers r distributed among the grains with any frequency ϕ. Let us now discuss the case of the existence of a whole range of sensitivities ϵ, while the quantum number r is common to all grains.

Let the number of grains endowed with an intrinsic sensitivity x to $x + dx$ be $Ng(x)dx$, where g is some function satisfying, of course, the condition $\int_0^1 g(x)dx = 1$. (By its very meaning, the "intrinsic sensitivity" of a grain is limited to the interval 0 to 1.) And let s be the number of quanta required for the developability of any grain. Then the proportionate number of developable grains will be

$$\frac{K}{N} = 1 - \int_{x=0}^{1} g(x) e^{-nax} \sum_{i=1}^{s-1} \frac{(nax)^i}{i!} dx$$

and, its derivative with respect to an.

$$\frac{1}{N}\cdot\frac{dK}{adn} = \frac{1}{(s-1)!}\int_{x=0}^{1} g(x)(nax)^{s-1}e^{-nax}dx.$$

On the other hand, we have, for N grains of equal sensitivity ϵ, and each calling for r quanta to be made developable,

$$\frac{1}{N}\cdot\frac{dk}{adn} = \frac{\epsilon}{(n-1)!}(na\epsilon)^{r-1}e^{-na\epsilon}.$$

Now, if an observed curve expressible by an r-quantic term and with sensitivity ϵ common to all grains is also to be represented by an s-quantic term, with the said distribution frequency $g(x)$ of sensitivities among the grains, we must have, for all exposures n, $dK/dn = dk/dn$, or

$$(an)^{s-r}\int_0^1 g(x)x^{s-1}e^{-anx}dx = \frac{(s-1)!}{(r-1)!}\epsilon^r e^{-an\epsilon}. \qquad (d)$$

This then (to hold for all n) is an equation for the unknown distribution function $g(x)$.

Manifestly, the equation (d) cannot be satisfied (for all n) by any choice of $g(x)$ if s is at all greater than r. In fact, if $n \to 0$, we have

$$(an)^{s-r}\int_0^1 x^{s-1}g(x)dx = \epsilon^r\frac{(s-1)!}{(r-1)!},$$

and if $s - r = m$ is a positive integer, the equation becomes

$$\epsilon^r\frac{(s-1)!}{(r-1)!} = O^m\cdot\int_0^1 g(x)x^{s-1}dx,$$

where O^m tends to zero as rapidly as $a^m n^m$. Since x and $g(x)$ are throughout <1, the integral cannot be made infinite by any choice of the form of the function g, and we have $\epsilon^r = 0$, which is absurd.

Thus we see that the number of quanta required for the developability of a grain *cannot* be made greater than r, no matter how cunningly the sensitivities ϵ are distributed among the grains.

It is equally easy to see that that number cannot be made *smaller* than r by any choice whatever of the frequency g of sensitivities. For, if $s < r$, the equation (d) becomes for $n \to 0$,

$$\int_0^1 g(x)x^{s-1}dx = 0,$$

and since x and $g(x)$ are essentially positive, the integral cannot be annihilated by any choice of $g(x)$.

In fine, then, s can neither be made greater nor smaller than r. The only alternative is $s = r$. Thus the originally found quantum number r (actually always a small integer) remains inviolable. The small number

r, pertaining to grains of equal sensitivity ϵ cannot be made greater nor changed at all, by attributing to the grains a whole range of ϵ's.[3]

We may now, at any rate, conclude this discussion by saying that *the quantum number* r itself, attributable to an observed curve, is *uniquely* determined. Neither an r-range nor an ϵ-range can change its value.

II. MACROSCOPIC DENSITY-EXPOSURE CURVES—"EXPONENTIAL" EMULSION

Any single, r-quantic term is now expressed by (1). Since this expression has been derived from the microphotographic one, (2), by integration over all grain sizes, our contention (of uniqueness), already proved in Part I, must of course hold also for the representation of a density-exposure curve.

In spite of this, we shall prove it here again in connection with the formula (1) as it stands. But since the proof (for each size-class of grains composing the emulsion) has implicitly been already given, it will suffice to consider here only a dispersity of the r-numbers (leaving the case of an ϵ-range as a good exercise for the reader).

Suppose, then, that an observed curve has been well represented by a single quantic term

$$\frac{D(y)}{D_m} = \frac{y^r(r+1+y)}{(1+y)^{r+1}}, \qquad y = \bar{a}\epsilon n,$$

where r has some fixed value (such as 1, 2 or 3). Assume, if possible, that the same curve can be represented by a superposition of such quantic terms, with quantum numbers $s = 1, 2,$ etc. ad infinitum, $N\phi(s)$ being the number of grains calling for s quanta. Then the distribution function $\phi(s)$ must be so chosen that

$$\sum_{s=1}^{\infty} \phi(s) \frac{y^s(s+1+y)}{(1+y)^{s+1}} = \frac{y^r(r+1+y)}{(1+y)^{r+1}},$$

for all exposures y. This equation, or rather identity, may be con-

[3] The necessary equation (d) can be satisfied *only* for $s = r$, when it is reduced to

$$\int_0^1 x^{\epsilon-1} g(x) e^{-\bar{a}\epsilon n x} dx = e^{\epsilon r} \cdot e^{\epsilon a n},$$

and since it is to hold for all exposures n, it breaks up into an infinite system of equations

$$\int_0^1 x^r g(x)dx = \epsilon^{r+1}, \qquad \int_0^1 x^{r+1} g(x)dx = \epsilon^{r+2}, \qquad \int_0^1 x^{r+2} g(x)dx = \epsilon^{r+3},$$

and so on. If $g(x)$ is an analytical function, say,

$$g(x) = c_0 + c_1 x + c_2 x^2 + \cdots,$$

we have, for the coefficients, c_0, c_1, etc., an infinity of linear equations,

$$\frac{c_0}{r+1} + \frac{c_1}{r+2} + \frac{c_2}{r+3} + \cdots = \epsilon^{r+1},$$

$$\frac{c_0}{r+2} + \frac{c_1}{r+3} + \frac{c_2}{r+4} + \cdots = \epsilon^{r+2}, \text{ etc.}$$

Their solution is of no interest, since the $g(x)$ thus determined implies $s = r$.

veniently written

$$\sum_{s=1}^{\infty} \phi(s) y^{s-r}(s+1+y)(1+y)^{r-s} = r+1+y. \tag{3}$$

To fix the ideas, consider the special case $r = 2$. Then

$$\frac{\phi(1)}{y}(2+y)(1+y) + \phi(2)(3+y) + \frac{\phi(3)y(4+y)}{(1+y)} + \frac{\phi(4)y^2(5+y)}{(1+y)^2} + \cdots = 3+y,$$

or

$$\phi(1)(2+y)(1+y) + \phi(2)y(3+y) + \frac{\phi(3)y^2(4+y)}{(1+y)} + \frac{\phi(4)y^3(5+y)}{(1+y)^2} + \cdots = 3y+y^2,$$

and since

$$(1+y)^{-1} = 1 - y + y^2 - \cdots,$$
$$(1+y)^{-2} = 1 - 2y + 3y^2 - 4y^3 + \cdots, \text{ etc.},$$

we have

$$\phi(1)(2+y)(1+y) + \phi(2)y(3+y) + \phi(3)y^2(4+y)(1-y+y^2+\cdots) + \phi(4)y^3(5+y)(1-2y+3y^2-4y^3+\cdots) + \cdots = 3y+y^2.$$

Since this is to hold for all y, the coefficients of any power of y on both sides must be equal. Thus, first of all, the constant term on the left must vanish, that is,

$$\phi(1) = 0,$$

which leaves us with

$$\phi(2)(3+y) + \phi(3)y(4+y)(1-y+y^2-\cdots) + \phi(4)y^2(5+y)(1-2y+3y^2-\cdots) + \cdots = 3+y,$$

whence $\phi(2) = 1$. This actually settles the question. For $\phi(2) = 1$ means that *all* grains call for $r = 2$ quanta, so that $\phi(3)$, $\phi(4)$, etc., must all vanish sharing the fate of $\phi(1)$. But we can prove formally this conclusion. In fact, since $\phi(2) = 1$, the last equation reduces to

$$\phi(3)y(4+y)(1-y+y^2-\cdots) + \phi(4)y^2(5+y)(1-2y+3y^2-\cdots) + \cdots = 0$$

and since the ϕ's and all their factors are non-negative, their sum can vanish only if

$$\phi(3) = \phi(4) = \cdots = 0.$$

In fine, then, $\phi(2) = 1$ and all other ϕ's vanish, which proves the uniqueness of the 2-quantic representation of the given curve. In much the same way, the reader will prove that, for any r, $\phi(r) = 1$ and all other $\phi(s) = 0$. This completes the proof of uniqueness in the case of a single r-quantic term.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

RAPID EXTRACTION OF RESINS FROM WILD RUBBERS

Chemists of the National Bureau of Standards have developed a simple method for converting wild rubbers having a high resin content into a product comparable to plantation rubber. This is accomplished by extracting a large portion of the natural resins from the wild rubbers.

The deresination studies were conducted by J. W. Wood[1] and Rachel J. Fanning of the Bureau staff as part of a research and testing program on natural rubbers sponsored at the Bureau by the Rubber Development Corporation of the Reconstruction Finance Corporation. Two Mexican wild rubbers obtained from the shrubs of Chilte and Guayule were chosen for the investigation.

Although synthetic rubber can be substituted for natural in the manufacture of many rubber products, and is actually superior for some of these uses, there are still other products which can be made only from natural rubber. This is true for many materials used by the armed forces. It was, therefore, necessary during World War II, when about 95 per cent of the world's supply of natural rubber was cut off, to make use of every bit of available natural rubber whether it was of good or inferior quality. Many types of wild rubber were collected from tropical America and Africa. Some were of such inferior quality that they had to be blended with better grades of rubber before they could be used. Others could be improved in quality by the extraction of their resins, which would give the resulting rubber a higher percentage of rubber hydrocarbon.

For experimental extraction of resins from wild rubber, the Bureau's chemists used a modification of a commercial solvent-tight mixer, designed for compounding heavy industrial pastes. Two S-shaped stainless-steel blades, operating within the extraction chamber, were rotated while solvent was passed into the chamber from a glass distilling apparatus. The same apparatus was also operated in another set of experiments without the blades rotating in order to compare the rubbers made both with and without mastication.

The Chilte rubber, which contained originally over 50 per cent of resinous material, required only 4 hr. of extraction when accompanied by mastication in order to reduce the resin content to that customarily found in plantation rubber of high quality. Even less time was required

* Communicated by the Director.

[1] Mr. Wood is now associated with the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Center, Beltsville, Md.

to reduce the 20 per cent original resin content of the Guayule to a comparable figure. Without the mastication the extraction process required more than 12 hr. to bring about similar reductions in the acetone-soluble material.

The tensile strengths of vulcanizates prepared from both types of rubber increased as greater amounts of acetone-soluble material were removed. The tensile strengths of the rubbers produced by the mastication process were greater than those of the rubbers prepared when no mastication was used. It was concluded from this investigation, therefore, that wild rubbers containing high percentages of acetone-soluble materials can be deresinated efficiently if mastication of the rubber takes place during extraction, and that the quality of the resulting rubber is greatly improved by the process.[3]

VOLUME DILATOMETRY

Scientists of the National Bureau of Standards have found the simple, inexpensive volume dilatometer to be a valuable research tool, not only for obtaining data on volume coefficients of thermal expansion, but also for studying phase changes in solids and liquids. Continued application of volume dilatometry at the Bureau over the past 15 years has resulted in improvements in technique and in simplification of the apparatus to such an extent that accurate dilatometers can now be made and used in almost any small laboratory.

Linear dilatometers of various types have frequently been used to advantage in determining the expansivity of metals and other solid materials. They cannot, of course, give correct results for liquids or for other fluid materials. In these cases the volume dilatometer can be used successfully; it has been shown to have a precision of about 1 per cent.

Primarily, the volume dilatometer measures the change of volume of a sample as it undergoes a change in temperature. Its secondary importance lies in the discovery of phase-changes and other transitions. Thus, if the density or volume of a substance is plotted as a function of the temperature, there will be anomalies in the otherwise smooth curve wherever there is a change of phase or other transition. These anomalies represent points at which a change occurs in the structure of the sample or in the types of motion by which it can absorb energy. They may or may not be accompanied by the release or absorption of heat.

Materials for the construction of the instrument consist of glass tubing of any convenient size and a calibrated glass capillary. The confining liquid may be mercury or any other substance which has a

[3] Further technical details will be published in a forthcoming issue of the *Rubber Age*.

known expansivity and which will not react with the sample. Uniform heating is provided by means of a bath containing alcohol, water, or a high-boiling oil, depending on the range of temperature to be studied.

The preparation and operation of the volume dilatometer may be described briefly as follows: A glass capillary is carefully calibrated and sealed to one end of a larger glass tube. The weighed sample is introduced into the tube, a glass bulb is added, and the tube is sealed. The bulb is used to prevent overheating of the sample during the sealing operation. The dilatometer is then weighed, evacuated, filled with mercury, reweighed, and then placed in a bath. As the bath is heated, the sample expands, forcing mercury up into the capillary where readings may be made. From the known weights and densities of the sample and the confining liquid and from the known expansivity of the confining liquid, the expansivity of the sample can be calculated. Corrections must be applied for entrapped air bubbles, nonuniformity of the capillary, and the thermal expansion of glass.

NOTE: For further technical details, see "Volume Dilatometry," by Normal Bekkedahl, *J. Research NBS*, Vol. 43, p. 145 (1949), RP 2016.

ABSORPTION OF OXYGEN BY ALKALINE PYROGALLOL

One of the most important reactions in gas analysis, believed for many years to be subject to unavoidable errors, has been found dependable by chemists of the National Bureau of Standards when a few simple conditions are met. The analytical absorption of oxygen by alkaline pyrogallol was previously rendered inaccurate by the formation of carbon monoxide in unpredictable quantities. Investigation of the problem by Marthada V. Kilday of the Bureau staff has resulted in a procedure which improves the accuracy of the analysis.[1]

The first step in the investigation was the selection of a suitable method for measuring the amount of carbon monoxide formed in any one reaction. Only when this was known could the conditions causing the production of carbon monoxide be found and corrected.

For this purpose, the NBS Carbon Monoxide Indicator,[2] developed during World War II, proved particularly suitable. The indicator, a yellow chemical that turns green on exposure to carbon monoxide, can be compared with known standards to give quantitative readings. It is most accurate for concentrations of carbon monoxide up to 0.1 per cent. Higher concentrations can be determined by diluting the sample.

A modification of the Shepherd gas analysis apparatus was used for the test reactions. Oxygen in known mixtures was absorbed in pyrogal-

[1] Marthada V. Kilday, "A Quantitative Study of the Carbon Monoxide Formed During the Absorption of Oxygen by Alkaline Pyrogallol," *J. Research NBS*, Vol. 45, p. 43 (1950), RP 2112.

[2] "Carbon Monoxide Indicator," *NBS Technical News Bulletin No. 354*, p. 73 (1946).

lol, and the residue was passed through the indicator. Here the amount of carbon monoxide was determined so that corrections could be made for it in the final computations.

The greatest source of error was found to be the method of preparing the pyrogallol solution. Heat produced by the reaction, if not carried away immediately, resulted in the formation of carbon monoxide in unpredictable amounts.

As a result of this work, the accuracy, reproducibility, and rapidity of the determination of oxygen by absorption in pyrogallol may be improved under the following conditions:

1. Solutions can be prepared that evolve no significant amount of carbon monoxide during the usual analysis. This is accomplished by the direct addition of a saturated solution of potassium hydroxide to pyrogallol crystals while the reaction vessel is immersed in ice water and closed to the atmosphere.

2. Samples having partial pressures of oxygen higher than 50 per cent can be analyzed with the *improved* solutions without dilution of the sample.

3. A pipette that disperses the gas in fine bubbles through at least 18 cm. of solution is preferable.

4. The rate of flow of the sample into the pyrogallol should be as rapid as possible and never less than 20 ml. per minute.

5. The temperature of the pyrogallol reagent should not exceed 30° C. during absorption.

6. If high accuracy is desired, the solution should not be used for analysis after 12 volumes of oxygen have been absorbed per volume of solution.

THE FRANKLIN INSTITUTE

MINUTES OF ANNUAL MEETING

January 17, 1951

The Annual Meeting of The Franklin Institute was held on Wednesday, January 17, 1951, in conjunction with the dinner of the Newcomen Society of England in North America celebrating the 245th Anniversary of Benjamin Franklin's birth. Over four hundred persons attended.

At the conclusion of the dinner, Mr. Ralph Kelly, Chairman of the Philadelphia Committee of the Newcomen Society, turned the proceedings over to President Nalle who conducted the Annual Meeting of the Institute.

President Nalle announced that the Minutes of the Stated Monthly Meeting for December are being printed in full in the January issue of the JOURNAL OF THE FRANKLIN INSTITUTE and will be presented for approval at the February meeting.

The Annual Report, Mr. Nalle stated, will be presented at a meeting in the Spring after receipt of the auditor's report.

The Secretary reported the following elections to membership for the month of December:

Active	25
Associate	25
Student	12

The total membership, as of 31 December 1950, was 5,951.

Along with his report, the Secretary announced the formation of a significant cooperative project with industry. The Franklin Institute Laboratories for Research and Development have organized a National Asphalt Research Center which is being supported by some twenty producers and users of asphalt. This Center will begin a research program on the basic properties of asphalt. The first meeting of the group will be held on January 29 with technical conferences during the day and an informal dinner that evening. Those interested are welcome to attend the dinner. Mr. Ralph Kelly will be the principal speaker.

The President called for the report of the tellers appointed in accordance with the by-laws to count the votes for the eight Managers to be elected. Dr. George S. Crampton, chairman, reported the total ballots cast and the number received by each candidate. All votes were cast for the following persons:

Morton Gibbons-Neff	Charles S. Redding
Hiram S. Lukens	S. Wyman Rolph
George Wharton Pepper	John Russell, Jr.
M. M. Price	Clarence Tolan, Jr.

The above named members were declared elected Managers of the Institute for a term of three years, and the President offered a vote of thanks to Dr. Crampton, Dr. Joseph S. Hepburn and Mr. Penrose Hoopes for their services as tellers.

The Secretary read the following report of the Elliott Cresson Fund as required by the deed of gift:

ELLIOTT CRESSON FUND

Report of the Trustees to the
Annual Meeting of The Franklin Institute

In 1848 Elliott Cresson gave $1,000 to two trustees to establish a trust fund, the income of which was to be used for the purchase of gold medals to be given to the Treasurer of The Institute and to be awarded by The Institute in accordance with the deed of gift.

The deed of gift provided that "annually at the stated meeting of the said Franklin Institute in the month of January the . . . [trustees] shall present to the said meeting a Statement of the accounts of their Trust showing the amount of the said principal sum, how the same is then invested, what interest or income has been received therefrom during the preceding year, what amount has been expended and for what purposes the number of medals delivered to the said Treasurer and the number thereof that he has delivered under the awards of the said Institute."

In accordance with the aforementioned provision, this report is submitted.

Elliott Cresson Fund Principal (representing the original $1,000 plus additions thereto from Unexpended Income)		$4 000.00
Invested as follows:		
$4,000 U.S. Treasury 2½% bonds, due 6/15/1962–67 at book value (Market $4,100)	$4 181.59	
Cash in Western Saving Fund Society and Fidelity-Philadelphia Trust Company	123.14	
	$4 304.73	
Income for 1950:		
Interest on bonds (less amortization)	$ 106.73	
Interest on bank balance	1.36	108.09
Expenses:		
Medal, case, and certificate for award of one medal	78.00	
Stationery	2.30	80.30
Unexpended income for year		$ 27.79
Unexpended income at beginning of year		$2 225.98
Additions during year as above		27.79
Unexpended income at end of year		$2 253.77
Invested as follows:		
$2,000 U.S. Treasury 2½% bonds due 6/15/1962–67 at book value (Market $2,050)	$2 091.26	
Cash in banks	162.51	
	$2 253.77	

HENRY B. ALLEN, *Trustee*
JOHN FRAZER, *Trustee*

Mr. M. M. Price presented Mr. Isaac Harter to receive the Newcomen Medal. Then Mr. Nalle, by virtue of the power vested in him as President of The Franklin Institute of the State of Pennsylvania, presented to Mr. Harter the Newcomen Medal with its accompanying Certificate and Report.

The chair was then returned to Mr. Kelly who conducted the further proceedings of the Newcomen Society.

HENRY B. ALLEN
Secretary

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS JANUARY 17, 1951

ACTIVE FAMILY

Frederick Rackwitz

ACTIVE

Dorothy Case-Blechschmidt (M.D.)
Lawrence M. Davies
Norman M. Haac
Fred Hague
Herbert V. Hurlbrink
J. Owen Kirkbride
Cyrus Klingsberg
Jacob L. Leister
Robert E. MacNeal
David Marder
Thorndike C. T. Niu
Fritz S. Poll
Blair K. Shellenberger
Frank L. Thomson
Adrian W. Voegelin, M.D.
Com. John C. Walter

ACTIVE NON-RESIDENT

Donald Patterson
D. J. R. Suffredini

NECROLOGY

John F. Bevan '43
David Furman '46
Viktor Goldschmidt '01
Arthur T. Hagstoz '43
Joshua A. Pearson '10
George W. Ramsey '16

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, January 10, 1951.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JANUARY 10, 1951.

MR. LEWIS P. TABOR in the Chair.

The following reports were presented for final action:

No. 3212: Work of Adams and Holmes in the Field of Synthetic Ion Exchange Resins.

This report recommended the award of a Howard N. Potts Medal each to Basil Albert Adams and Eric Leighton Holmes, both of England, "In consideration of their pioneering concept of the use of suitably designed synthetic organic resins for ion exchange, the discovery of anion exchange, the application of these principles to the preparation without distillation of pure water, and paving the way for the tremendous subsequent development in ion exchange materials and processes in science and industry."

No. 3229: Work of C. M. Foust.

This report recommended the award of a Howard N. Potts Medal to Clifford M. Foust, of Schenectady, New York, "In recognition of his many contributions to the knowledge of high-voltage surge phenomena and the quantitative measurements furthering this knowledge through his development of accurate measuring devices."

JOHN FRAZER,
Secretary to Committee.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

DRAEMEL, MILO F.: Protection and Conservation of Pennsylvania's Water Resources.
GROSS, ERIC T. B. AND LEONARD RABINS: Transient Analysis of Three-Phase Power Systems.
ORDUNG, PHILIP F. AND HERBERT L. KRAUSS: Frequency-Coordinate Vector Diagram.
DRENICK, R.: The Perturbation Calculus in Missile Ballistics.
STAUDER, W. V. AND A. H. WEBER: Electron Diffraction Studies of Etched Gold Leaf Films.
SILBERSTEIN, LUDWIK: Macroscopic Sensitometry, Opacity and Photographic Density, Specular and Diffuse.
MOON, PARRY AND DOMINA EBERLE SPENCER: Modeling with Light.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M.; Wednesdays and Thursdays from 2 P.M. until 10 P.M.

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MUSEUM

The National Board of Underwriters has classified fires in three major categories: those which may be defined as incipient fires in ordinary combustible materials, such as paper, wood, rags, etc.; those which are incipient fires in small quantities of inflammable liquids such as oil, gasoline, paint, etc.; and those which are incipient fires in electrical equipment.

In the first category are those fires of the commonest order where the quenching effect of water is of first importance. The other two categories offer a graver problem. Nothing is quite so terrifying as the fire which results when an inflammable liquid bursts into flame. It flames with such paralyzing suddenness and is spread rather than quenched by deluging with water. Since some of the inflammable liquids have to be stored in very large quantities, gasoline is an example, extraordinary precautions have to be taken against the possibility of fire. Largely because of the development of an efficient foam distributing system for blanketing such fires, the danger from them has been greatly dispelled.

The idea of using a foam blanket is not entirely new. It was first introduced nearly fifty years ago, but no practical system was developed until a few years ago. The museum has been fortunate in obtaining a working exhibit from the National Foam Company, West Chester, which demonstrates the excellence of the foam idea.

It would be well to distinguish between froth and foam. Although there is no sharp line of division it may be said in general that froth is composed of relatively large bubbles and the surface tension of the bubble film is relatively weak, easily broken by stirring or touching. Foam consists of very small bubbles filled with carbon dioxide gas, well bonded together and not easily separable or broken. The foam substance comprises basically two parts, the foaming agent and the stabilizer which strengthens the bubble film and increases its surface tension. When a solution of sulphate of alumina is used, a stabilizer is added which strengthens the surface tension of the hydroxide of alumina because it toughens the foam formed by the reaction of the sulphate of alumina with bicarbonate of soda.

Formerly, the action of sulphuric acid on a solution of bicarbonate of soda was used to create a foam, but instead it created a froth which was not stable. This froth had a negligible fire extinguishing property, its value being due to the cooling effect of the liquids. When a solution of sulphate of alumina was substituted for sulphuric acid, it was found that its reaction with bicarbonate of soda produced a rather dense froth. The surface tension of the bubbles, however, was still insufficient to class the product as a foam, and it had little practical value as an extinguishing agent. The bubble film in this case is composed largely of hydroxide of alumina and this compound plays an important part in the production of foam. The hydroxide of alumina is a colloidal or gelatinous substance which is very well suited for forming the film of bubbles. It does not, however, possess sufficient surface tension to enable it to confine the gas within the bubbles long enough for them to be of practical value in extinguishing fire. Hence the need for a dependable foam stabilizer.

One of the early methods tried for the production of foam was to bubble carbon dioxide gas through an ordinary soap solution. This produced a foam which was effective in extinguishing fire, but there were several objections to the use of this method, principally the fact that the soap did not have sufficient surface tension to form strong, durable, heat-resisting bubbles. Other substances were tried, such as glue, glucose, saponin, and licorice.

The volume of foam produced by an extinguisher will vary with a number of factors. Assuming temperature and pressure conditions to remain constant, and equal quantities of chemicals are used, the volume of foam will depend upon the quantity of gas confined in the bubbles, and the surface tension of the bubble film itself. Abnormally high expansion and large bubbles indicate a weakness on the part of the foam stabilizer; it does not mean that more gas is produced or that a larger portion of it is imprisioned in the bubbles.

The National Foam Company's exhibit demonstrates how a fire of alcohol is swiftly extinguished and it indicates how the extinguisher may be developed into a distributing system for application on a large scale when there is a wide distribution of tanks containing inflammable liquid.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

A BIBLIOGRAPHY ON SONIC AND ULTRASONIC VIBRATION: BIOLOGICAL, BIOCHEMICAL AND BIOPHYSICAL APPLICATIONS

BY

GEORGE M. NAIMARK, JANE KLAIR AND WILLIAM A. MOSHER

INTRODUCTION

The need for an extensive bibliography on the biological applications of sonic and ultrasonic vibration prompted the compilation of this bibliography as a guide to the literature in this field.

Original publications were consulted whenever possible; in all other cases secondary sources were utilized.

The references are grouped chronologically and arranged alphabetically by senior author within each year. Abstract journal references are given when available, even though the original publication has been consulted. In cases of multiple authorship, all authors are listed in the author index. Unsigned articles are listed as "Anon." at the beginning of each yearly group. All titles are in English. Abbreviations and style of references are patterned, in the main, after *Chemical Abstracts*.

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ED. NOTE: Author and subject indices for this bibliography will be published in the March issue of this JOURNAL.

BOOK REVIEWS

THEORY OF THE INTERIOR BALLISTICS OF GUNS, by J. Corner. 443 pages, illustrations, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1950. Price, $8.00.

Dr. Corner's book emphasizes methods of tackling interior ballistic problems and outlines various theories which can be employed. For each method presented, the assumptions upon which the theory is based and the weaknesses of the theory are clearly outlined. The author keeps very close to theoretical considerations and only touches on experimental methods when they help to clarify the ballistic theory.

As an introduction to actual ballistic calculations, the author describes briefly the practical side of the field, including such items as proof firing, acceptance and pressure, and velocity measurements. The characteristics of propellants, composition, shape and form function are discussed. Theories of burning are outlined and various factors affecting burning rate are discussed. These include erosion of the propellant, initial temperature, thermal conductivity of the flame, and turbulence. A chapter is devoted to the thermochemistry of propellants and methods are presented for correlating the characteristics of propellants with chemical composition and closed bomb tests.

The first ballistic method described by Dr. Corner is a simple method which is used as the basis for charge determinations in British practice. This method requires a great deal of empirical data on weapons of similar type in order to be used effectively. Working formulas are given and solutions of these formulas are included to show the dependence of velocity and pressure upon the characteristics of the gun, projectile and propellant.

More advanced ballistic methods requiring fewer assumptions are described. One solution due to Coppock treats accurately the covolume and the cooling of the gases up to the all-burnt position. Comparisons of theoretical and experimental values are shown. Goldie's and Clemmow's solutions, which show the effect of "shot-start" and effect of burning rate not proportional to pressure, respectively, are also presented in detail. Numerical and mechanical methods of solution of the equation encountered in more advanced interior ballistic theories are described.

Similarity relations are derived for the simple set of ballistic equations and the transformation is described by which solutions for different guns may be generalized for a set of consistent parameters. Among these generalized solutions are the tabular and graphical solutions of Bennett, Charbonnier-Sugot and Röggla.

Interior ballistic theories for special types of guns are included. Among these are theories for recoilless guns, worn guns, tapered bore guns and the so-called high-low pressure gun. It is demonstrated that there is small room for improvement in piezometric efficiency with the high-low principle.

A review of Lagrange's ballistic problem relative to pressure, density and gas velocity between the breech and the base of the projectile is included. Also, there is some discussion on the results of Love and Pidduck regarding wave motion within the chamber and the bore. The author presents a theory on the motion of the gas in the bore after the projectile has left. In conjunction with this, there are included some theoretical data on muzzle brakes and methods are given for determining their thrust and efficiency. Some data on heat transmission coefficients and heat transfer to the gun tube are presented in the final chapters of the book.

In general, the book covers quite thoroughly British interior ballistic methods, classical theories and allied problems in interior ballistics. The presentation of simple methods and more exact theories makes the book a useful reference both for the ordnance engineer and the ballistician.

R. H. MARVIN

NEW ATOMS, by Otto Hahn. 184 pages, diagrams and tables, 14 × 20 cm. New York, Elsevier Publishing Co., Inc., 1950. Price, $1.75.

The team of Hahn, Strassmann, and Meitner were the pioneers in the discovery of fission of the uranium nucleus. Otto Hahn, the senior member, has here presented a clear, simple

account of the nuclear reactions involved in the fission process, and of the historical development of our knowledge of the subject.

The first chapter is Prof. Hahn's Nobel Lecture, delivered when he was awarded the Nobel Prize for Chemistry in 1944. In it he summarizes rapidly the steps that led from the first studies of neutron bombardment of the very heavy nuclei to the realization that fission of the nuclei was taking place in these experiments. Chapter II, retracing in more detail some of the material in the first chapter, discusses the character of these fission reactions, the chain reaction, the roles of U235 and U238 in the pile, production of plutonium, and industrial and explosive uses of the new energy sources. In the third chapter, the artificial new elements 43, 61, 85, 87 and 93 to 98 inclusive are discussed in detail, including methods of production, chemistry, etc. The place of the transuraniums 93 to 98 in the Periodic Table is briefly discussed. The fourth and last chapter is devoted to Prof. Hahn's personal reminiscences of the early days of radiochemistry.

In summary, the book is very clearly and simply written, and not too technical in detail. It is the sort of book most useful to scientists in other branches who have caught but a glimpse of the tremendous recent developments in this field. It would also make an ideal source book for chemistry classes at the college level, particularly because almost nowhere else is this much material on the subject of the chemistry of fission and the transuraniums gathered together.

A. D. FRANKLIN

ULTRAHIGH FREQUENCY ENGINEERING, by Thomas L. Martin, Jr. 456 pages, diagrams and illustrations, 15 × 22 cm. New York, Prentice-Hall, Inc., 1950. Price, $6.00.

It is refreshing to read a textbook on the subject of ultrahigh frequency engineering and to find that the author has actually devoted his book to the subject matter on a high level. Professor Martin's mature book for senior students in electrical engineering is devoted to a general study of techniques associated with UHF systems. Detailed emphasis is laid on unit or component engineering design, that is, the design of the building blocks from which entire systems are constructed. This allows the student to develop and understand concepts associated with the fundamental theory; generalized examples are always presented to help develop technique.

The eleven chapters in the book cover six major subjects: generation and synchronization of special wave forms, amplification, transmission, circuit elements, oscillators, and propagation. The sections on wave shaping and trigger circuits are especially well written. Clear detailed explanations describing the operation of these circuits are accompanied by numerous line diagrams and oscilloscope traces and followed by general design procedures. A useful table lists design constants for fifteen circuits discussed in these chapters.

Wide band amplifiers are analyzed especially with respect to compensation and the effects of cathode degeneration; i-f. amplifiers are covered but briefly.

The remaining eight chapters are concerned with ultrahigh frequency engineering problems on the following subjects: transmission lines as circuit elements; wave guides and cavity resonators; triode, klystron, and magnetron oscillators; and ionospheric propagation and the effects of changes in the electromagnetic constants of the atmosphere.

Most of the chapters close with a collection of thought-provoking design problems; all chapters have extensive bibliographies. This reviewer is of the opinion that such a book could be used effectively for its intended purpose in many schools of electrical engineering. It is highly recommended to electronic engineers and physicists who encounter design and operating problems in ultrahigh frequencies.

S. CHARP

NEGATIVE IONS, by H. S. W. Massey. Second edition, 133 pages, diagrams, 14 × 22 cm. New York, Cambridge University Press, 1950. Price, $2.50.

A unique and satisfying combination of theory and experimental data and description is contained in this book on negative ions in the gas phase at pressures lower than a few mm. of Hg. Details on the methods of determining such quantities as electron affinities are followed by discussions of the results and their interpretations according to quantum mechanical ideas.

Nowhere does the author try to include the more involved mathematical reasoning of the quantum mechanics, but he does make much use of the physical results of the theory in correlating what is known about negative ions with the rather extensive knowledge of neutral atoms and molecules.

The first two chapters are devoted to a brief discussion of the structures of negative ions, formed atoms and molecules, and the experimental methods used to determine electron affinities. The third chapter deals with processes which lead to negative ion formation. Types of capture of electrons by atoms or molecules and the modes of appearance of the resulting liberated energy are discussed, in each case with introductory remarks on the theory of the processes followed by descriptions of the experimental methods used and the general results. The reverse processes are considered in chapter four, where the problem is the detachment of electrons from negative ions. Here the author, because experimental data on reaction probabilities and energies are lacking, makes use of theory almost entirely. In the last chapter a discussion of the influence of negative ions in glow discharges leads to consideration of their role in the phenomena observed in the upper atmosphere and in the solar and stellar atmospheres.

Quite generally, this appears to be a most excellent summary of our knowledge of the properties and behavior of negative ions. It is exceptionally clear and understandable, and apparently quite up-to-date. It should be excellent source material for student and teacher in atomic physics, or for those working in the fields of spectroscopy, glow discharges, astrophysics, and a host of other subjects in which negative ions are important.

—A. D. FRANKLIN

INTRODUCTORY NUCLEAR PHYSICS, by David Halliday. 558 pages, diagrams, tables and illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $6.50.

Introductory Nuclear Physics, by David Halliday, is a book which is intended primarily for use as a text in courses for advanced undergraduate or beginning graduate students.

After a very brief historical introduction at the beginning of the first chapter, the author devotes several paragraphs to a discussion of "operational philosophy," in which the validity of a theory is determined by the number of experiments which it can describe in a simple and accurate manner. This viewpoint is widely accepted in modern scientific thought and is particularly important in nuclear physics. The remainder of the first chapter deals with basic nuclear concepts, including discussions of the size and mass of the nucleus, the equivalence of mass and energy, and the properties of nuclear particles. The next four chapters deal with charged particles and photons. Their production, detection, and interaction with matter are discussed in considerable detail. The chapter following these is devoted to a discussion of neutrons and methods for their detection.

Among the topics treated in the remainder of the book are nuclear masses, relative mass abundances, nuclear forces, nuclear reactions, nuclear fission, and cosmic rays. There is also a chapter on charged particle accelerators which includes descriptions of the electrostatic generator, linear accelerator, cyclotron, synchrocyclotron, betatron, synchrotron, and the bevatron. The book also contains two appendices containing a list of physical constants and a short resumé of recent developments in nuclear physics which occurred too late to be included in the body of the book.

The book contains numerous illustrations, nearly 300 altogether, many of which are taken from recent scientific literature. There are many excellent problems which serve to amplify the material in the text. A novel feature of these problems is that many of them employ actual data taken from research publications. In each case where such data are used the periodical reference is given, thus enabling the student to obtain further information.

This book should not only prove useful as a text but should also be valuable as a reference book, since it reports results of the important research in nuclear physics from the beginning of the science through the early part of 1950.

MARSHALL D. EARLE

ORDINARY NON-LINEAR DIFFERENTIAL EQUATIONS IN ENGINEERING AND PHYSICAL SCIENCES, by N. W. McLachlan. 201 pages, diagrams, 16 × 24 cm. Oxford, Clarendon Press, 1950. Price, $4.25.

Since the purpose of this text is to provide an *introduction* to the subject, it is appropriate to define the "ordinary, non-linear" part of the title for the beginner. By an ordinary differential equation is meant one in which there is a single independent variable, so that the derivatives are ordinary derivatives (as distinct from partial derivatives). A differential equation is called non-linear in the dependent variable when the degree of the dependent variable and/or its derivatives differs from unity, or if they occur as products. The author limits the text to ordinary non-linear differential equations except for an appendix on sound waves in a loudspeaker horn, in which a *partial* non-linear differential equation is considered.

The author points out correctly that the literature contains many articles on application but neglects the theoretical side of the subject. Nevertheless, he goes on to state: ". . . the text is confined chiefly to the presentation of various analytical methods employed in the solution of important technical problems . . . Accordingly the book is *not* an analytical treatise with technical applications. It aims to show how certain types of non-linear problems may be solved, and how experimental results may be interpreted by aid of non-linear analysis."

The contents of the book include: General Introduction, Equations Readily Integrable, Equations Integrable by Elliptic Integrals and Functions, Equations Having Periodic Solutions, Method of Slowly Varying Amplitude and Phase, The Equivalent Linear Equation, Equations Having Periodic Coefficients, and Graphical and Numerical Solutions.

In addition to the previously mentioned appendix, another treats a method of using Mathieu's equation as a stability criterion of the solutions of non-linear equations. Exercises appear only as part of the body of the text, but in that capacity comprise much of the book. The references and cross references number over three hundred.

The graphical solution presented is the familiar method of isoclines accompanied by the usual figures. Indeed, the main contribution of the book is not that it offers anything fundamentally new, but that it gathers under one cover a considerable amount of work done in a field that is rapidly expanding. Its publication at this time when the pure mathematician is showing interest in the subject and the government is sponsoring research in non-linear problems should result in a circulation reflecting the need for such books.

D. B. HOUGHTON

RADIO COMMUNICATION AT ULTRA HIGH FREQUENCY, by J. Thomson. 203 pages, 14 × 22 cm. London, Methuen & Co.; distributed by John Wiley & Sons, Inc., 1950. Price, $4.50.

Professor Thomson has performed a distinct service for the electronic engineer who is interested in the implications and applications of the techniques of ultra high frequency electronics developed in the past decade. Both the specialist who perhaps has difficulty in seeing the forest for the trees and the engineer who is interested in a concise survey, will find this volume stimulating and informative.

With a minimum amount of engineering details and with strong emphasis on physical principles, the author surveys the problems involved: circuits, tubes, frequency control, modulation techniques, and communications systems.

Especially noteworthy are his discussions of the unsolved problems, a feature far too often completely neglected in engineering texts and reference books. For these reasons, this volume, while topical, will not soon be relegated to that section of the bookshelf reserved for books read but never reread.

FRANK T. INNES

NUMERICAL MATHEMATICAL ANALYSIS, by James B. Scarborough. Second edition, 511 pages, diagrams, 16 × 24 cm. Baltimore, The Johns Hopkins Press, 1950. Price, $6.00.

The first edition of this well known work has long been a helpful tool for those scientists and engineers who had need for a source of information on interpolation and accuracy of interpolation, numerical differentiation, integration, and the solution of equations as well as

on the precision of measurements and curve fitting. The second edition enlarges to some extent on the subjects covered in the first edition in that chapters have been included on the numerical solution of partial differential equations and on integral equations. The chapters on the numerical solution of ordinary differential equations and on numerical integration have been thoroughly revised and enlarged. Throughout the book the errors of the first edition have been corrected and the subject matter has been elaborated. Scarborough's approach is distinguished by its clarity in the development of mathematical methods, and by the meager demands made on the reader's mathematical sophistication. A reader who has had at most an introductory course in differential equations is adequately prepared to use and understand this book. This reviewer recommends that this book be part of the working equipment of any technical man who has need to use numerical mathematical analysis.

EZRA KRENDEL

BASIC ELECTRICAL MEASUREMENTS, by Melville B. Stout. 504 pages, illustrations and diagrams, 15 × 22 cm. New York, Prentice-Hall, Inc., 1950. Price, $5.75.

This excellent book starts appropriately with a chapter on the history of electrical measurements. The second is entitled Experimental Procedure; Errors. It includes a list of elements that should be on every data sheet. Too often those gathering the data are not the ones who must analyze them. Were the author's suggestions followed, the analysis would be simpler, whether performed by an outsider or by the engineer who conducts the experiment. A discussion of basic statistical measures of central tendency and spread, probable error, and significant figures is also in the second chapter. A brief chapter on aids to computation is followed by one on measurement of resistance which speaks of ohmmeters, voltmeter-ammeter method, Wheatstone bridge, Kelvin bridge, and Thevenin's Theorem. Considerable use is made of Thevenin's Theorem throughout the rest of the text whenever opportunity permits. Galvanometers, shunts, potentiometers and their applications in basic electrical measurements complete the first eight chapters.

The next few chapters are concerned with various types of bridges—their titles: Alternating-Current Bridges, Additional Measuring Circuits, Measurement of Mutual Inductance, Shielding-Shielded Bridges, Characteristics of Bridge Components, and Bridge Accessories. The discussion of a-c. bridges is particularly thorough. The concluding chapters are Instrument Transformers, Magnetic Measurements, and Electrical Indicating Instruments.

In all cases the author has stuck closely to his subject. Don't expect to see a discussion of sine, cosine or logarithmic potentiometers in a section headed special purpose potentiometers; mention of special or general purpose analogue computation as a field in which bridges and potentiometers are finding use, or radar and television under a section on the uses of the cathode-ray tube. Discussions of equipment are limited to their applicability in basic electrical measurements.

The author has given references and exercises at the end of each chapter. They are numerous and well-chosen. The book would make a fine text for an electrical engineering course and is being so used at the University of Michigan. The author wisely suggests that such a course in the science of measurements should come after the student has acquired some background and maturity in electrical matters and has considerable facility in handling circuits.

D. B. HOUGHTON

AN AUTOBIOGRAPHY, by Sir Arthur Keith. 721 pages, plates, 14 × 22 cm. New York, Philosophical Library, Inc., 1950. Price, $4.75.

The history of science is sprinkled with the names of great workers who sprang from humble families and who, by the exercise of their own sterling qualities, rose to positions of eminence in their field. Here is an altogether delightful addition to their numbers. Born of Scottish farming parents, Sir Arthur Keith was able to struggle through college and to obtain a medical degree only by family sacrifice. Unable to buy a medical practice and wishful to secure a position on some college faculty, he was compelled to accept a post in Siam. Here he began his study of the anatomy of monkeys. When the company for whom he was working went bankrupt, he returned to England and became lecturer in anatomy at the School of

London Hospital. Five years later he was appointed Conservator of the museum of the Royal College of Surgeons, a position he was to hold with increasing distinction for twenty-four years. At the grand age of eighty-four he is still master of the College experimental farm, which was his own conception.

If asked to describe his occupation, Sir Arthur would probably say he was an anatomist, but he was early plunged into the study of anthropology and it is in this field he is most commonly known. As early as 1916 he became identified with a definite school of anthropology. He was convinced by his anatomical studies that the physical features which distinguished one race of mankind from another were due to the actions of hormones. As an anthropologist he began to question how families inheriting the effects of an overaction of the pituitary hormone were prevented from dispersal. Evolution required that members of the family be isolated. Discarding such isolating features as mountain ranges, wide deserts, great rivers, and the ocean, Sir Arthur learned that aborigine people regarded the fellow members of their group as friends, and all outsiders as their enemies. From which he concluded that the machinery of isolation was not physical but mental.

The new theory of evolution gained adherents but it also provided him with opponents. Sir Arthur has never shrunk from controversy, although he never deliberately provoked one.

His life as he here presents it has been a full one almost to the point of frenzy, for his mind has always been at work, his eye ever observant. He had early ambitions and he did not hesitate to flagellate himself to attain them, although he was sparing of others. Now that all he sought, and more, has come to him, he sets down the record of successes and failures with a refreshing candor. His wit is of the type a Scot would describe as "pawky," and he uses it unsparingly against himself.

Since a large part of a man's biography lies in the making of friends, Sir Arthur does not neglect this aspect of his busy life. There is a long succession of sharply drawn portraits of the distinguished men who crossed his path, and some warmly human pictures of the less-famous.

It is a revealing book in which self-esteem never distorts the picture. Where Sir Arthur was in error he does not hesitate to admit his fault, and he displays a praiseworthy generosity to others when he speaks of broken friendships. He had many friends in this country, and those who know him only by the popular articles he contributed to the New York *Times* ought to be grateful for this book which admits them to a more intimate picture of his multitudinous interests. The general reader will find many interesting glimpses of life on a Scottish farm, of London life in late Victorian and Edwardian days, and of scientific observation while pursuing the daily avocations of life. Countrybred, he retained an eye for country. The scientist, especially medical men, will find a wealth of illuminating comment on men and manners as well as information upon the development of surgery and anthropology during the past sixty years.

Sir Arthur was not a notable lecturer because he always had so much to say he experienced difficulty in crowding it all into the allotted time. His writings, on the other hand, have been noted for their compactness and clarity. Writing in a new medium Sir Arthur has occasionally permitted trivia to intrude into his narrative, but the reader readily forgives these lapses in the admirable narrative of a long and profitable life.

T. C.

FUNDAMENTALS OF OPTICS, by Francis A. Jenkins and Harvey E. White. Second edition, 647 pages, illustrations and diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., 1950. Price, $7.00.

In this second edition of a text well-known to all students of optics, the authors have extended the scope of their book to include a treatment of geometrical optics and the quantum behavior of light as well as their original treatise on physical optics. The book in its expanded form has thus become a complete, comprehensive reference source for this important field of study.

The first part of the book, consisting of ten chapters devoted to geometrical optics, presents a thorough-going survey of this entire subject, treating plane and spherical surfaces,

thin and thick lenses, and spherical mirrors. In addition separate chapters are spent on the effects of stops, the often neglected subject of ray-tracing, lens aberrations, and the application of the principles outlined to the construction of optical instruments. In all of these first chapters illustrative numerical examples are included; these are set off from the text itself by horizontal lines to point them out.

Part II contains 19 chapters dealing with the wave nature of light and the phenomena which can be explained on the hypothesis that light consists of waves—interference, diffraction, absorption and scattering, spectra of light sources, dispersion, polarization, refraction, optical activity, reflection, and magneto and electro-optical effects. Included in these chapters are many striking photographs of interference and diffraction fringes and spectra. Another feature which enhances the usefulness of the book as a text for a course in optics is the inclusion throughout this section of descriptions of illustrative demonstration experiments which can be set up in the lecture room. These experiments are set off from the rest of the text in the same manner as the numerical examples of Part I.

The mention of various recent developments in the field, such as the phase contrast microscope, the interference filter, and the electron microscope brings this section on physical optics very much up to date.

The book is concluded with a single chapter on quantum optics. Entitled "Photons," this chapter treats briefly the evidence for light quanta, the development of quantum mechanics, and the interpretation of the dual character of light.

Comprehensive problems are included at the end of each chapter of the text, with the answers to all the even-numbered ones given at the back of the book.

Fundamentals of Optics in the opinion of the reviewer should prove indispensable, both as a text book for an advanced undergraduate course and as a reference source for all engaged in work in the field of optics. Its treatment of geometrical and physical optics is skillful and complete. The section on the quantum aspects of light, though not as exhaustive as the other two parts, serves as a useful guide to the major considerations involved.

JEAN A. MINKIN

TOOL ENGINEERING, by Lawrence E. Doyle. 499 pages, diagrams, illustrations and tables, 15 × 22 cm. New York, Prentice-Hall, Inc., 1950. Price, $4.75.

Tool Engineering, written by a man who has been many years in industry and now returned to teaching, presents the problems and means of solution arising in planning and tooling for production. It is an elementary book and written for college students. The pattern of each chapter—introduction, detailed discussion, illustrative problems, summary, numerous questions on the chapter's contents, and bibliography—is well adapted for easy comprehension.

Following an introduction on the nature and scope of tool engineering, Professor Doyle proceeds to discuss the elementary principles of economics, planning and tooling for economy, principles of estimating and planning practices. Then, delving into the process side of tool engineering, he presents the principles of dimensioning, process requirements, conditions and operations, principles of locating workpieces, tool design and clamping principles.

E. W. HAMMER, JR.

FUNDAMENTALS OF ACOUSTICS, by Lawrence E. Kinsler and Austin R. Frey. 516 pages, tables and diagrams, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $6.00.

The purpose of this book as stated in the preface is to present the fundamental principles involved in the generation, transmission, and reception of acoustic waves.

The book is intended primarily as a text and is written in such a way that it can easily be used in either a one or a two semester course. The first nine chapters deal principally with the production, propagation, and absorption of sound waves. This group of chapters should be sufficient for a short course in which the emphasis is on theory rather than applications. Among topics discussed in this part of the book are: simple harmonic motion; vibrations in strings, bars and plates; plane and spherical acoustic waves and transmission and absorption phenomena. There is also a chapter containing a good treatment of resonators and filters.

The next seven chapters are devoted to the applications of acoustics. The first three of this group deal with the theory and design of loudspeakers and microphones. The titles of the remaining chapters are: Psychoacoustics, Architectural Acoustics, Underwater Acoustics, and Ultrasonics.

Emphasis is placed on the close association of acoustics with communication engineering. The authors also take advantage of the fact that electrical analogues can be very useful in the solution of acoustical problems. Each chapter is followed by a set of problems. Many of these problems deal with practical situations and should be valuable in aiding the student in the application of his knowledge. The terminology used in the book is that proposed by the American Standards Association.

The authors have made no attempt to make the book a comprehensive reference work. As a text, however, it is quite complete and its presentation of the subject is clear and well organized. It should prove particularly useful in engineering courses.

MARSHALL D. EARLE

TELEVISION, Volume V (1947-1948), edited by Alfred Goldsmith and others. 461 pages, diagrams and illustrations, 15 × 23 cm. New Jersey, Radio Corp. of America, 1950. Price, $2.50.

TELEVISION, Volume VI (1949-1950), edited by Alfred Goldsmith and others. 422 pages, diagrams and illustrations, 15 × 23 cm. New Jersey, Radio Corp. of America, 1950. Price, $2.50.

Electronic engineers and physicists are no doubt familiar with the RCA Technical Book Series. *Television, Volumes V* and *VI* are two publications in this group, devoted to reprints of technical papers in the subject field which appeared in the years 1947–1948 and 1949–1950. The papers were published originally in various journals; all are authored by RCA personnel.

Each volume separates the papers into six sections: pick-up, transmission, reception, VHF, color, and general. A detailed review of each paper is out of place here. It will suffice to list some of the outstanding subjects: image orthicon and vidicon pick-up tubes; transmitter transient response and interlocked scanning systems; metal kinescopes, receiver high voltage power supplies, co-channel and adjacent channel interference, deflection circuits, and intercarrier sound systems; VHF timers, transmitters, antennas, and complete experimental systems; dot sequential sampling principles and systems; television in industry and electro-optical characteristics of television systems.

Most of the papers are extremely well written and illustrated. They are authoritative and can serve as basic references for further work in this subject. Since much of the material and techniques described are incorporated into present television transmitter and receiver systems, these volumes should also be of interest to technical people who own television sets and who wish to learn more about the operation of their equipment.

S. CHARP

SPACE-TIME STRUCTURE, by Erwin Schrödinger. 119 pages, diagrams, 14 × 22 cm. New York, Cambridge University Press, 1950. Price, $2.75.

This book has grown out of the author's lecture notes on tensor analysis and its applications in field theories, especially the Special and the General Theories of Relativity and their generalizations by Einstein and Strauss on the one hand and by the author on the other.

The originality of thought which led the author to the formulation of the wave equation bearing his name forming the basis of the wave-mechanical approach to quantum physics, shows itself in the presentation of the concepts which play a most important part in the invariant formulation of field physics.

In concise, yet very lucid, language, the author introduces the concepts of scalar, vector and tensor (of any rank) in terms of the behavior of their components on transformation of coordinates, and the concept of invariance on transformation. He proceeds to give the rules of tensor algebra, referring to quantities defined at a single point, and, thence, to tensor analysis, referring to quantities at neighboring points, and enumerates those differential operators which are invariant on transformation in a four-dimensional unconnected manifold.

The concept of affine connection between the elements of a continuous manifold is introduced in a novel manner, by stipulating that the operation of invariant differentiation should obey the product rule of ordinary differentiation and should reduce to it when applied to an invariant.

A discussion of the equivalence of the "affinities" so defined with those defined in the conventional manner in terms of parallel transfer should prove to be a valuable aid in gaining insight into the concept of an affinely connected manifold.

The curvature tensor is introduced as being that tensorial quantity whose vanishing is the necessary and sufficient condition of integrability of an affine connection.

A discussion of relations holding true on any single geodesic of an affinely connected manifold serves to bring out the fact that a comparison of lengths (which is a metrical concept!) is possible along a single geodesic, but that it is impossible to compare lengths defined along two different geodesics, even when they cross each other.

The metrical tensor is then introduced as that tensorial quantity which must be specified at every element of a continuous manifold to render these lengths comparable.

The author points out and demonstrates that it is possible to develop the greater part of the Special and the General Theories of Relativity in terms of an affinely connected four-dimensional manifold, and that, on this view, the introduction of a specific metric into this manifold is equivalent to a specification of the physical properties of space-time, which is analogous to the introduction of "material equations" in the classical field theories.

The remaining half of the book is devoted to an analysis of the Special and the General Theories of Relativity, and their later extensions, in the light of the concepts introduced in the first half. In addition to exhibiting the formalism of these theories, the author gives a very lucid interpretation of the concepts which this formalism embodies.

The present reviewer feels that this "visualization" of the "conceptual maps" of the Theories of Relativity constitutes the most valuable part of this excellent book, which will, no doubt, provide a strong stimulus for a further extension and elaboration of these concepts to its competent readers.

O. R. SPIES

PHYSICAL CHEMISTRY OF HIGH POLYMER SYSTEMS, by H. Mark and A. V. Tobolsky. Volume 2, 506 pages, illustrations, diagrams and tables, 15 × 23 cm. New York, Interscience Publishers, Inc., 1950. Price, $6.50.

Because of the extensive progress made in most branches of polymer science since the publication of the first edition in 1940, the authors have completely revised the text. There are thirteen chapters including condensed discussions on molecular structure and intra- and intermolecular forces.

More detailed information is given in the chapters concerning the thermodynamic and kinematic properties of polymer solutions. Properties such as vapor pressure, osmotic pressure, depression of freezing point and elevation of the boiling point are discussed in their relation to molecular weight determination.

In many cases viscosity is an essential criterion of quality for solutions used industrially; therefore, many standard technical methods have been devised for its measurement. Recently viscosity measurements have become an important means of determing molecular weight.

The ultracentrifuge provides an excellent means for measuring molecular weight or particle size in solution. If the material is not of uniform particle size, the degree of non-uniformity can be determined. This technique also permits mechanical fractionation of mixed macromolecules from the fluids in which they are found.

The concluding chapters deal with the methods of polymerization and polymer degradation.

The inclusion of numerous references to the original literature and a complete subject and author index make this text an extremely valuable aid in further study of the physical chemistry of high polymers.

ANNE M. BUCHY

CIRCUIT ANALYSIS OF A-C POWER SYSTEMS, Volume II, by Edith Clarke. 396 pages, drawings and diagrams, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1950. Price, $8.50.

This volume is the newest of a series written in the interest of the General Electric advanced engineering program. Although Edith Clarke is now professor of electrical engineering at the University of Texas, a large portion of her professional work was done in the employ of the General Electric Company so that the viewpoint of practical engineering is present in her writing.

The book presents methods for determining the performance of a-c power systems under various operating conditions. The electrical characteristics of insulated cables, power transformers, synchronous machines and induction motors are treated from the standpoint of analyzing the behavior of power networks. The construction of these devices as well as their principles of operation and mathematical relations necessary for computing performance is summarized. The word, summarized, is used here to imply that the many large subjects covered in this single volume can only be portrayed fundamentally and not in the detail of the professional periodical paper. However, the source papers, usually *AIEE Transactions*, are cited in chapter bibliographies so that the student or engineer may refer to the more detailed disclosure if required.

A well developed reference on electric power systems, this book should be useful to engineers concerned with transmission problems and central station engineering. The general impedance chart is widely used throughout the book for representing system characteristics. In many instances the author discusses the conditions which attend faults or abnormalities of circuits encountered when working with numerous kinds of industrial installations. Equivalent circuits and vector diagrams are freely used to complement the mathematical treatments.

Since the successful operation of a power system depends to some extent upon the maintenance of adequate equipment protection, a chapter is devoted to thorough discussion of this subject exclusive of lightning protection. The latter is adequately covered in another of the General Electric series, "Protection of Transmission Systems Against Lightning," by W. W. Lewis.

Briefly, the book could serve as an adequate text for teaching purposes, a number of problems having been given together with their worked-out solutions. Through appreciation of the many representative curves and tables the student would gain a fair working knowledge of practical equipments and be in a position to assist at least with some elementary engineering designs.

C. W. HARGENS

STRUCTURAL CARBOHYDRATE CHEMISTRY, by E. G. V. Percival. 246 pages, diagrams, 14 × 22 cm. New York, Prentice-Hall, Inc., 1950. Price, $5.50.

There has been a great need for modern treatises on carbohydrate chemistry particularly in the English language. Until recently, information on cellulose, starch, polysaccharides, and the oligosaccharides has been quite scattered and out of date. Percival, in this book, attempts to partially fulfill the need by presenting the most recent advances in carbohydrate chemistry from the standpoint of structure.

The introduction (Chapter I) acquaints the beginner with the general properties, stereoisomerism, configurations, transformations, and interrelationships of the monosaccharides. Chapter II discusses the sugars as ring forms and offers a system of nomenclature. The next two chapters are devoted to some of the reactions that sugar molecules undergo. Chapter V gives extensive coverage to the oligosaccharides and Chapter VI introduces the subject of the polysaccharides. The five remaining chapters contain detailed information on polysaccharides such as cellulose, starch, the uronic acids and polyuronides, natural glycosides, polyhydric alcohols, and polysaccharides containing heterocyclic atoms.

The author skillfully traces the development of carbohydrate chemistry through the presentation of proofs of structures and characteristic reactions. This is accomplished particularly well in the chapters devoted to the nomosaccharides and oligosaccharides. Unfortunately, the part of the book on polysaccharides is not as detailed as it should be, perhaps

due to publishing restrictions. The use of both the standard "ladder" type configurational formulae and the modern plane projection type is somewhat confusing but does facilitate the understanding of the stereoisomerism of sugar molecules.

The book presents a difficult and complicated subject in a clear and succinct manner. The author intends the book for students "reading for an Honours Degree" and as a text for courses in carbohydrate chemistry. It is also to be recommended to reasearch workers in the field as well as a valuable addition to the chemist's library.

D. H. RUSSELL

CHEMICAL THERMODYNAMICS, by Irving M. Klotz. 369 pages, diagrams and tables, 15 × 23 cm. New York, Prentice-Hall, Inc., 1950. Price, $6.00.

This text, in the Prentice-Hall Chemistry Series, is an introductory treatment of the subject from the phenomenological viewpoint. The statistical viewpoint is excluded entirely because the author believes that the statistical approach should be based on a previous introduction to quantum-mechanical concepts and should be presented as an independent and complementary treatment with emphasis on the broader scope. The outstanding feature of this book is the extensive use of sub-headings in outline form to indicate the position of a given topic in the general sequence of presentation. The first section begins with a chapter on mathematical apparatus followed by chapters covering the first, second and third laws, enthalpy, heat capacity, free energy, heat of reaction and various applications. The second section of the book is concerned with systems of variable composition introduced by a chapter on partial molal quantities.

The subject matter covered is the same as that of Lewis and Randall, but the order of presentation is different. Almost every chapter contains examples of analytical and graphical methods of solving various problems encountered by the chemist and, in addition, there are numerous exercises for the student.

On opening the book, this reviewer was impressed by the orderly arrangement, the printing and the paper, but, after reading it, felt that less space should have been given to simple mathematical steps, graphical and arithmetic methods. One should expect that students of chemistry have an adequate mathematical background for this subject. The mathematical introduction could be improved considerably. The author's use of DW and DQ, which he calls inexact differentials, to represent small quantities of work and heat, respectively, is a departure from the usual treatment and is confusing. Aside from the above criticism, it is believed that the attempt to write an introductory text suitable for a one-semester course has, in general, been successful.

W. E. SCOTT

BOOK NOTES

NATURAL AND SYNTHETIC HIGH POLYMERS; A TEXTBOOK AND REFERENCE BOOK FOR CHEMISTS AND BIOLOGISTS, by Kurt H. Meyer. Second edition, 821 pages, illustrations, 16 × 24 cm. New York, Interscience Publishers, 1950. Price, $15.00.

The rapid development of the field of polymer chemistry since the appearance of the first edition of this work in 1942 has necessitated the almost complete rewriting of the text. In addition, some two hundred pages of new material have been added, including a new chapter on Elasticity, Viscosity, and Plasticity of High Polymers. This continues a comprehensive work in which the author has endeavored to review all pertinent material from a critical viewpoint.

MODERN AIR-CONDITIONING, HEATING AND VENTILATING, by Willis H. Carrier, Realto E. Cherne, and Walter A. Grant. Second edition, 574 pages, illustrations, diagrams and tables, 18 × 26 cm. New York, Pitman Publishing Corp., 1950. Price, $10.00.

This revised edition of a standard work includes a new section on radiant and panel heating, new techniques in air cleaning and purification, a fundamental treatment of automatic

controls for air conditioning and new material on axial flow fans. A particular feature is the psychometric chart prepared by Dr. Carrier. Problems have been added to this edition covering both the theoretical and practical aspects of the subject matter.

TEXTBOOK OF ORGANIC CHEMISTRY, by Louis F. Fieser and Mary Fieser. 741 pages, diagrams, 16 × 24 cm. Boston, D.C. Heath and Co., 1950. Price, $6.00.

The authors here present an introductory college textbook in organic chemistry which offers the same development of fundamental principles presented in their larger *Organic Chemistry* second edition, except for a few changes. It does omit certain topics covered in the larger work. A feature of this volume is the inclusion of comprehensive summaries of each chapter, problems and complete answers.

FUNDAMENTALS OF THE CALCULUS, by Donald E. Richmond. 233 pages, illustrations, 15 × 23 cm. New York, McGraw-Hill Book Co., 1950. Price, $3.00.

The author recognizes the need for a firm grounding in the fundamentals of calculus and at the same time he desires to promote a feeling for the logical beauty of mathematics. Thus, this text aims to provide a combination of the practical and theoretical with due consideration of the algebraic shortcomings of many students. The problems have been designed to promote understanding of the text, and not to be an end in themselves.

GENERAL CHEMISTRY, by L. E. Young and C. W. Porter. Third edition, 608 pages, illustrations, 16 × 24 cm. New York, Prentice-Hall, 1950. Price, $4.25.

In preparing this revision of an elementary text in chemistry, the authors have endeavored to meet the criticisms and suggestions of those teachers who have written them. The principal change has been to move forward the sections on acids, bases, salts and ionization to permit the use of ionic equations in the major part of the text.

AIRPLANE DESIGN MANUAL, by Frederick K. Teichmann. Third edition, 382 pages, tables and diagrams, 15 × 23 cm. New York, Pitman Publishing Corp., 1950.

This comprehensive book on airplane design problems and techniques now appears in a third edition. New material has been added and tables have been incorporated giving much recent design information.

TELEVISION SERVICING, THEORY AND PRACTICE, by Walter H. Buchsbaum. 340 pages, diagrams and illustrations, 16 × 24 cm. New York, Prentice-Hall, Inc., 1950. Price, $5.35.

In preparing this text on television, the author has divided his material into three parts. He explains first the theory on which television operates with many examples and illustrations. The second part covers step-by-step procedures for the alignment and installation of the television receiver. Finally, in the third part, are given suggestions for trouble-shooting the TV receiver.

ADVANCED ORGANIC CHEMISTRY, by Reynold C. Fuson. 669 pages, illustrations, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1950. Price, $8.00.

In preparing this textbook on organic chemistry for students desiring an advanced knowledge, the author has employed an organization of subject matter differing from the classical one of elementary texts. This follows from his belief that a student re-examining facts and theories will benefit more if the material is presented in a context different from that already familiar to him. Thus an arrangement by type reactions has been employed, and actual examples of synthetic value have been chosen for illustrative purposes. In the selection of reactions for discussion, the author has been guided by the current interests of research workers as disclosed by their publications.

CURRENT TOPICS

Remote Control Dictation System Announced.—In a revolutionary approach to handling business correspondence, Thomas A. Edison, Incorporated has developed a new system of "remote control" dictation. The TeleVoice System, as it is called, consists of from one to twenty modified telephones directly connected to a central recording instrument located near the secretary.

The recording instrument, called the Edison TeleVoicewriter, records the dictation received on plastic discs. Transcription of the dictated matter is accomplished with the standard Edison Disc Secretarial Unit.

The TeleVoice Stations (phone extensions) can be located any distance from the TeleVoicewriter. Each Station gives the dictator every one of the services he needs to dictate easily and accurately, including a means of listening back to what he has said and the facility for recording corrections.

Unlike individual dictating machines, the dictator has only those functions to perform which are a direct part of actual dictation. The secretary takes care of changing the discs and index slips. Since the work is delivered to her by direct wire, her flow of work is even and messenger services are minimized.

Provision is made in the system for eliminating conflict between dictators who might wish to use it simultaneously. Because only dictators with a low volume of letter writing are put on the TeleVoice System, the chances of finding the "line in use" are only one in four and even then there is only a one minute wait, according to the Company, because the average letter is only 120 words long. The Company states that the vast majority of those who dictate are "low volume dictators." A positive warning signal in the form of a small red light on each phone goes on when the system is being used, making it unnecessary to pick up the receiver and listen to find out if all is clear.

Heavy volume dictators or those doing confidential work are normally given individual Disc Edison Voicewriter recording instruments, which record on the same disc records as the TeleVoicewriter.

The result, according to the Company, is the first completely integrated system for business dictation—a dictating system that, because of its low cost (only half that of individual machines), makes possible instrument dictation service to every letter or memo writer even though his daily output may be very small.

Five years of research and trial installations have proved the TeleVoice System the fastest and most economical letter writing system ever devised. The Company further reports that TeleVoicewriting has been tried out extensively in hospitals to expedite the handling of medical records which were previously written 80% in longhand. It has been found that with TeleVoice, all hospital records can be made to include two or three times as much information and in one third of the time previously required of doctors. Experience in commercial installations indicates enthusiastic reception by all hands—management because of low cost and high efficiency, dictators because phones are natural and easy to use, and secretaries because the work flow is steady, voices change frequently on the same disc, and there is less changing of discs and index slips since all discs come through fully used.

TeleVoice Stations (extensions) are made in both desk type and mount type phones. On each phone base is just one button and the signal light. This button is used both for making corrections and for listening back. In the handle is a "talk switch" that is held down during dictation; it starts and stops the disc on the TeleVoicewriter recording instrument. The dictator records correction marks on the index slip by pressing the button located on the base of the TeleVoice extension while holding the "talk" switch down. To listen back the dictator presses the base button only. Length marks on the index slip are automatically recorded by "hanging up." These features assure the secretary the same ease of transcription she now enjoys with the standard Disc Edison Voicewriter.

While as many as twenty TeleVoice Stations can be wired to one TeleVoicewriter recorder, the average for commercial installations is ten. The number of stations to be used initially is determined by a survey of the work load of each dictator involved. Thereafter it is a simple matter to add more extensions if personnel is increased or more central recording units if the work load increases sufficiently to require it. Naturally, anyone who has an extra heavy volume of dictation is given an individual machine, but such people are in the minority, the Company says, because the system permits immediate answering of letters and eliminates "saving up" correspondence until enough has accumulated to call in the stenographer.

The TeleVoice System, Edison says, is especially important at this time because it saves both secretarial and dictator manhours at a time when the country needs them, and does so while using less critical materials than individual dictating machines. Government offices now trying to expand to handle the emergency have already found a serious shortage of trained stenographers. The TeleVoice System provides one answer since it employs a minimum of secretarial personnel, compared with the shorthand method.

New RCA Electronic Computer Aids U. S. Air Defense.—The largest and most accurate electronic analogue computer ever built to evaluate the performance of guided missiles, ships, airplanes, submarines and aid in the air protection of American cities today was shown in operation publicly for the first time at a joint Navy Special Devices Center–Radio Corporation of America demonstration.

"Designated 'Project Typhoon,' the new electronic computer is expected to save many millions of dollars in the design of guided missiles and also solve many riddles encountered in the air defense of our cities," said Dr. C. B. Jolliffe, Executive Vice President in Charge of RCA Laboratories Division. "Complex simulated problems of a complete guided missile system, which other computers are too small or too inaccurate to handle effectively, can be solved by Typhoon. This will enable the design of equipment with a minimum of experiments that would require expensive apparatus, such as missiles, airplanes and ships."

Dr. Jolliffe predicted that the RCA electronic analogue computer will play a significant role in military science of the future. Very often the construction of an experimental guided missile may cost more than $100,000, he pointed out, and unless its characteristics are properly checked in advance by accurate computing techniques, actual launchings may be failures resulting

in the loss of instruments and apparatus. With Typhoon, he added, any missile problem can be solved over and over, with the characteristics varied each time until the desired results are obtained. Thus, by avoiding costly trial and error tests, the new computer can, with a high degree of accuracy, assure scientists how a proposed missile will react under actual flight conditions.

The new analogue calculator employs approximately 4000 electron tubes, several miles of intricate wiring and a new set of superaccurate components, exact to better than one part in 25,000. Under contract with the Special Devices Center of the Office of Naval Research, engineers of RCA Laboratories designed and built the instrument for use by the Navy Bureau of Aeronautics. Three years of research and development work directed by Arthur W. Vance, Head of the Electronic Computer Section of RCA Laboratories, preceded actual construction of the computer.

At the demonstration, the computer was shown solving a simulated air defense problem wherein a high-speed bomber was successfully attacked by a radar-controlled, supersonic rocket-propelled guided missile. The missile was guided with deadly accuracy to the target.

All information necessary to solve the problem was introduced to the machine by means of more than 100 dials and a portion of 6000 plug-in switchboard connections, mounted on the tall panel sections of the computer. Different dial positions and plug connections represented such characteristics as aerodynamics of the missile, loss of weight due to fuel consumption, and radar signals which follow the missile and target. Other adjustments accounted for the autopilot or gyro stabilizers of the missile, the path and velocity of the target, and the main guidance system to be used for directing the missile toward the target in the most effective manner.

An instant after the computer was put into operation by the throwing of a switch at the main control console, electrical impulses flowed through Typhoon's thousands of electron tubes and wires. Within the device, electrical currents and voltages began representing physical things such as distance, velocity and force. Circuits started functioning according to predetermined equations.

While the instrument was engaged in its electronic thinking process, the paths of both the high-speed bomber and the rocket-propelled guided missile were traced respectively by red and green pens on two large plotting boards. From these charts, which provided a permanent record of the test flight, skilled technicians were able to determine the exact position of the missile at any given time.

A three-dimension visual representation of the "dog fight" as it progressed was provided for spectators by an auxiliary device, called the trajectory model, in which two suspended fluorescent balls traveled the identical course of the missile and target. At the same time, a small scale missile model, 12 in. long and 3½ in. in diameter, moved about on a rotating mechanism to simulate performance of the anti-aircraft missile under test. As the model received control signals or instructions from the computer describing how best to hit the target without wasting too much time or fuel, its three sets of fins were deflected as the corresponding fins of a missile would be deflected in actual flight.

While the solution proceeded, twelve recording voltmeters drew curves on

paper rolls indicating the positions of the fins, acceleration, velocity, and rate of spin of the missile, as well as the remaining distance between missile and target. Six sets of flashing neon lights on the panels of the computer displayed numbers representing the rates of spin, and the sidewise and forward velocities of the missile.

After only 60 seconds of operation, the computer automatically stopped and the solution was examined. RCA engineers then took the complete answers and explained what factors were right or wrong and how to make changes for better results.

Solution of the problem involved 250 additions, 67 multiplications, 30 integrations, and 20 aerodynamic functions, all carried on simultaneously with continuously variable factors. A mathematician and an assistant would require 6 months to compute a single solution for the minimum number of points required to give an approximate answer. Typhoon gave the continuous solution, for an infinite number of points, in less than 60 seconds.

A staff of nine engineers and mathematicians as well as six technical assistants is required to operate the computer when it is solving complex guided missile problems. To keep the sensitive instrument free of climatic influences, Typhoon is housed in a special air-conditioned room at RCA Laboratories which has a constant temperature of 75° Fahrenheit and a relative humidity of not more than 50 per cent.

Chloromycetin Used to Treat Influenzal Meningitis.—Twenty children in New Orleans and Houston, Tex., have had "gratifying and encouraging" recoveries from influenzal meningitis following treatments with Chloromycetin, the antibiotic made by Parke, Davis & Co.

Drs. Margaret H. D. Smith and George W. Prather, both of New Orleans, explained that prior to the use of Chloromycetin, 63 to 90 per cent of patients with this type of meningitis survived. However, even in well-equipped hospitals, many of the survivors showed evidence of permanent brain damage, so that odds for complete recovery were only 44 to 73 per cent.

The New Orleans physicians used Chloromycetin for 5 to 14 days in treating 15 unselected children, from six weeks to nine years old. Eight children were less than a year old, an age group in which recovery was less likely to occur.

All of the New Orleans children were free of symptoms when released from the hospital, excepting one who showed some weakness in an arm and leg when discharged on the 21st day. The physicians reported he was completely recovered a month later.

Three Houston physicians—Drs. W. William Carabelle, Donald D. Mitchell and George W. Salmon—reported the complete recovery of five children treated with Chloromycetin.

They said many of the patients, ranging in age from 6 to 24 months, were acutely ill from influenzal meningitis when first treated. There was some degree of rigidity in all.

Sulfadiazine, streptomycin and penicillin had failed in the case of one child, a nine-month-old girl. Her temperature was 102 degrees when she first received Chloromycetin, but thereafter never rose above 100. The physicians reported the girl's recovery as "uneventful."

All of the Houston children recovered without any apparent after-effects from the disease, the physicians said.

BY-LAWS

ARTICLE I

Stock

Section 1. The Real and Personal Estates of the Institute as held upon the First day of January, One Thousand Eight Hundred and Eighty-one, shall be valued at One Hundred Thousand Dollars, and shall be represented by Ten Thousand Shares of Stock of the par value of Ten Dollars each. Said shares shall be divided into two classes, *viz.:*

First Class. Shares not registered for use: on which no annual payment shall be charged or collected, and the holders thereof shall not have the privileges of members of the Institute, but may, if of legal age, vote at any annual election for managers upon the payment of One Dollar upon each share of stock on which they may desire to vote; provided, however, such shares have been held by the same person at least three months before such election.

Shares of the First Class may be converted into shares of the Second Class at the pleasure of the owners, provided the transfer be approved by the Board of Managers; but, when once so converted, they shall always continue in the Second Class.

Second Class. Shares registered for use: on which Twelve Dollars per annum shall be due and payable from resident members in advance on the first day of October in each year, except as hereinafter provided.

Non-resident holders of Second Class stock shall pay an annual fee of Five Dollars.

Section 2. The holders of Second Class stock shall be entitled to the use of the library, lectures and reading-room, and if of legal age, to all other privileges of membership in the Institute, so long as they make the annual payment in advance; and shall, on the payment of One Dollar therefor, be entitled to a Certificate of Membership.

Section 3. If the annual dues for successive years remain unpaid at the expiration of two and a half years on any share of stock of the Second Class, such shares shall then become forfeited to the Institute; but such forfeiture may be remitted by a unanimous vote of the Board of Managers.

Section 4. Stock of the Second Class may be held in trust for persons not of legal age, and shall be liable to the payment of only one-half the annual fees due upon stock of Second Class held by persons of legal age; provided, that when such minors arrive at legal age, new certificates, subject to the full annual contribution, shall issue on payment of the customary fee.

Section 5. Certificates for the First Class stock may be issued for any number of shares in a single certificate; but every certificate for the Second Class shall be for one share only.

Section 6. No share of stock in the Second Class shall be transferred until all arrearages and fines are paid, and all books and tickets returned, and the transfer approved by the Board of Managers.

Section 7. All certificates of stock shall be signed by the President and Secretary; shall be issued by the Controller, and shall be transferable only on the books of the Institute by the owner, or his legal representative, on the surrender of the old certificate, and of a fee of twenty-five cents for each certificate.

Section 8. All subscriptions to stock shall be approved by the Board of Managers before the certificate can be issued.

ARTICLE II

Members

Section 1. All persons interested in the purposes and activities of the Institute and willing to further them may become members when elected by the Board of Managers, or in a manner prescribed by the Board, except as qualified by Section 6 of this Article. Membership shall consist of the following classes:

1. Student members
2. Associate members
3. Active members
4. Sustaining members
5. Honorary members

The Board of Managers may establish other classes of members, provided that the privileges enjoyed and dues paid by such other classes are not inconsistent with the privileges and dues of the classes of members specifically provided for by these By-Laws.

Section 2. Student members shall be under twenty-five years of age and shall pay annual

dues of $2.00. They shall be entitled to unlimited free admission to the Museum and the Planetarium. Student members who are fourteen or more years of age may, if endorsed by a teacher or an Active member, have the use of the library upon the payment of additional annual dues of $1.00 but shall have no voting privileges or rights to hold office.

Section 3. Associate members shall pay annual dues of $5.00. They shall be entitled to unlimited free admission to the Museum and to the Planetarium, but shall have no voting privileges or rights to hold office. Upon the payment of $5.00 additional annual dues they shall have Family privileges as defined in Section 7 of this ARTICLE.

Section 4. Active members shall be not less than twenty years of age. They shall pay annual dues of $15.00. Active members, residing permanently at a distance of fifty miles or more from Philadelphia, shall pay annual dues of $7.50. Active members shall be entitled to use the library, to receive one copy of the Journal of The Franklin Institute, to vote and to hold office. They shall be entitled to all the privileges of Associate members and upon the payment of $5.00 additional annual dues shall be entitled to Family privileges.

Section 5. Sustaining members shall be not less than twenty years of age. They shall pay annual dues of not less than $50.00. They shall be entitled to all of the privileges of Active members and shall have Family privileges as defined in Section 7 of this ARTICLE free of additional charge.

Section 6. Honorary members shall be entitled to all of the privileges of sustaining members, except the right to vote and to hold office. They shall be nominated by the Board of Managers and shall be elected by four-fifths of the votes of the members present at any stated meeting of the Institute at which their nomination may be acted upon.

Section 7. Family privileges consist of the right to receive a card for each individual in the family of the member and resident with the member entitling the holder to unlimited free admission to the Museum and the Planetarium.

Section 8. Members belonging to classes of membership existing prior to the amendment of this ARTICLE shall be reclassified in a manner consistent with their former dues and privileges.

ARTICLE III

PAYMENT OF DUES

Section 1. The annual fees for membership shall be due and payable on the first day of each month, whichever is nearest to the date of election or as determined by the Board of Managers.

Section 2. Any member whose dues are more than two months in arrears shall have all the privileges of membership suspended until such time as all arrears are paid. Should the dues not be paid when they become six months in arrears the said member shall forfeit his membership.

Section 3. The Board may remit temporarily in whole or in part the dues of any member either by action in a particular case or by establishing regulations governing certain cases.

Section 4. Every person admitted to membership in the Institute shall be considered as liable for the payment of dues until he shall have resigned, been dropped or have been relieved therefrom by the Board of Managers.

Section 5. Resignations of memberships shall be made to the Board of Managers in writing, but need not be accepted until all dues and arrears up to date of resignation shall have been paid.

Section 6. The privileges and title of Associate member may be obtained for life by paying therefor in one year the sum of $100. From this payment may be deducted one-half of the Student or Associate Membership dues paid by the member during the preceding ten years, but in no case shall the deduction exceed $50.00.

Section 7. The privileges and title of Active Member shall be enjoyed for life or may be obtained for life by a member who has heretofore or who shall hereafter pay therefor, in one year, the sum of $300, except that a person residing permanently at a distance of twenty-five miles or more from Philadelphia may become an Active Member for life by paying therefor in one year the sum of $100. From this payment may be deducted one-half of the dues paid by the member during the preceding ten years, but in no case

shall the deduction exceed one-half of said payment. Associate Members for life may become Active Members for life by paying therefor in one year the sum of $200.

Section 8. Firms, corporations, associations or individuals may nominate and subscribe for the membership dues of groups of members of any class or classes, at the annual dues provided for, subject to the approval of the Board as to any particular nominee. If the dues of these nominees amount to $100 or more in the aggregate, the firm, corporation, association or individual shall be known as an Affiliate of the Institute.

ARTICLE IV

MANAGEMENT

Section 1. The Institute shall be governed by a board of twenty-four (24) Managers elected by the members.

Section 2. The officers, who shall be elected by the Board of Managers, shall be a President, an Executive Vice President, not more than five Vice Presidents, a Secretary, an Assistant Secretary, a Treasurer, and an Assistant Treasurer. The Board of Managers may elect such other officers as it deems necessary.

Section 3. At the annual meeting of the Institute, eight Managers shall be elected each year to serve for three years, provided that the Managers now elected, or who may hereafter be elected, shall continue to serve until their successors be appointed.

Section 4. All elections of the Institute shall be by letter ballot and no vote may be cast by proxy.

Section 5. Nominations for Managers shall be made in writing at the stated meeting in the month of December. Each nomination paper must be signed by at least two members, who shall certify that the candidate will serve if elected. After the nominations are closed, the President shall appoint three members, who are neither officers nor nominees, to act as tellers of election. The list of nominees shall be posted at the Institute and incorporated (with directions for voting) in a ballot to be sent to each member by the Secretary at least one week before the date of election. Each ballot shall be accompanied by a return envelope addressed "To the Tellers of Election," and provided with a space for the signature of the member voting.

Section 6. On the date of the annual meeting, and at an hour previously designated by their chairman, the tellers shall meet at the Institute, and shall count all legal votes that have been received by mail or placed in the ballot box before eight o'clock P.M.; and when the count is completed they shall report to the annual meeting of the Institute the total number of ballots cast, together with the number of votes received by each candidate. Thereupon the presiding officer shall announce the names of the candidates who received the plurality of votes, and shall declare them elected Managers of the Institute for the ensuing terms.

Section 7. At the organization meeting of the Board of Managers, the Board of Managers shall elect the officers provided for in Section 2 of ARTICLE IV to serve for one year; and may at said organization meeting or from time to time thereafter elect such other officers as it may determine upon, and shall determine and fix the compensation, if any, to be paid to the officers so elected or appointed by them. The officers who are in office immediately prior to the annual meeting shall continue in office until their successors are elected or appointed by the Board of Managers as herein provided.

Section 8. Vacancies occurring in any office may be filled by the Board of Managers by election or appointment of persons to serve until the next annual election.

ARTICLE V

BOARD OF MANAGERS

Section 1. The Board of Managers shall have general charge and control of the Institute and of the Benjamin Franklin Memorial and The Franklin Institute Museum, and shall consist of twenty-four members elected as provided in ARTICLE IV. The President, the Executive Vice President, the Vice Presidents, the Secretary, the Treasurer, the Chairman of the Committee on Science and the Arts, and the Chairman of the Library Committee shall be *ex officio* members. A quorum of the Board of Managers shall be nine of the elected and *ex officio* members. The Board of Managers may adopt such by-

laws, rules and regulations for the governance of their affairs as are not inconsistent with the Charter and these By-Laws.

Section 2. They shall present, through the President, at the annual meeting of the Institute, a report of the condition of the affairs of the Institute.

Section 3. They shall hold stated meetings in each month except in July and August.

Section 4. Special meetings may be called by the President at his discretion and shall be called by him on written request of the Executive Committee or of any seven members of the Board. In case of his absence or refusal to act, such special meeting shall be called by the Secretary.

Section 5. Members who have not attended five regular meetings in the twelve months prior to the stated meeting of the Institute in December, shall be reported thereat as having resigned, unless it be unanimously voted by the Board at that meeting that such member has been absent for sufficient reason.

Section 6. All vacancies on the Board of Managers shall be filled by the Board until the next annual meeting of the Institute.

Section 7. The Board of Managers may elect an Executive Committee consisting of five of its Members with such authority to act on behalf of the Board as the Board may delegate.

ARTICLE VI

DUTIES OF OFFICERS

Section 1. The President shall be the executive head of the Institute and, under the supervision of the Board of Managers, shall have general charge of the affairs of the Institute. He shall preside at all meetings of the Institute and of the Board of Managers and shall be, *ex officio*, a member of all standing committees of the Institute.

Section 2. The Executive Vice President, under the supervision of the President, shall have immediate charge of all affairs of the Institute other than those matters specifically delegated by action of the Board of Managers pursuant to these By-Laws to the Executive Committee and the Finance Committee. He shall prepare the annual budget, and submit it to the Board of Managers for approval. He shall be an *ex officio* member of all standing Committees of the Institute. He shall report to the President. In case of the disability of the Executive Vice President, the President shall designate another officer or other officers to assume his duties.

Section 3. In the absence of the President, the Executive Vice President shall exercise his duties. In the absence of both the President and the Executive Vice President, the Vice Presidents shall exercise the duties of President in order of their seniority in office.

Section 4. The Secretary shall be responsible for keeping the minutes of all meetings of the Institute and of the Board of Managers, shall keep the records of the Institute, and shall perform all the duties usually pertaining to the office of Secretary. He shall report to the Executive Vice President. In the absence or disability of the Secretary, the Assistant Secretary shall perform his duties.

Section 5. The Treasurer shall have custody of all monies received from the Committee on Finance together with all monies received by the Institute from dues, admissions, and other operations of the Institute, depositing them, in the name of the Institute, in such bank or banks as the Board of Managers shall direct and disbursing them by checks signed as the Board of Managers shall likewise direct. He shall keep accounts of the receipts and disbursements and shall report thereon to the Board of Managers as directed. He shall have general supervision of the accounts of the Institute and shall render such financial statements as directed by the Board of Managers. He shall give bond to an amount and with such surety as the Board of Managers shall determine. The Treasurer shall report to the Executive Vice President. In the absence of the Treasurer, the Assistant Treasurers shall, in the order of their seniority in office, perform his duties.

ARTICLE VII

BOARD OF COUNCILLORS

The Board of Councillors shall consist of not more than fifty members and shall embrace, as *ex officio* members, the Governor of Pennsylvania, the Chief Justice of the Supreme Court of Pennsylvania, the Mayor of the City of Philadelphia, the President of the

City Council of Philadelphia, the President of the Board of Public Education and the Superintendent of Schools of the City of Philadelphia, the Provost and the President of the University of Pennsylvania, the President of Commissioners of Fairmount Park, the President of the American Philosophical Society, the President of the Poor Richard Club, and the President and Secretary of The Franklin Institute, which two latter shall respectively be Chairman and Secretary of the Board of Councillors. Additional members shall be nominated by the President or Secretary of the Institute and elected by the Board of Managers, at such intervals as the Board of Managers may see fit. The Board of Councillors shall meet at the call of its Chairman or of the Board of Managers for the consideration of any matter that pertains to the welfare of the Institute. The Secretary shall from time to time send to the members of the Board of Councillors a report of the activities and accomplishments of the Institute.

ARTICLE VIII

COMMITTEES OF THE INSTITUTE

Section 1. There shall be the following Standing Committees of the Institute:

1. Bartol Research Foundation Committee.
2. Biochemical Research Foundation Committee.
3. Committee on Science and the Arts.
4. Endowment Committee.
5. Finance Committee.
6. Library Committee.
7. Meetings Committee.
8. Membership Committee.
9. Museum and Memorial Committee.
10. Publications Committee.
11. Committee on Research.

Section 2. Each standing committee of the Institute shall consist of the number of members determined on by the Board of Managers and composed of members of the Board of Managers and/or non-members as may be desirable, except that the Committee on Science and the Arts shall consist of not less than sixty nor more than seventy-five members, and except that the Bartol Research Foundation shall consist of not less than ten nor more than fifteen members as provided for in Section 7 of this ARTICLE.

Section 3. The members of each committee shall serve one year, except that members of the Committee on Science and the Arts shall serve three years.

Section 4. The members of each committee, other than *ex officio* members specifically provided for by these By-Laws, shall be appointed by the President and approved by the Board of Managers at the organization meeting of the Board following the annual meeting except that each year but one-third of the total number of members of the Committee on Science and the Arts shall be so appointed and approved.

Section 5. The Chairman of each Committee shall be designated by the President, except that the Library Committee and the Committee on Science and the Arts shall select their chairmen. A chairman who is not an elected or *ex officio* member of the Board of Managers shall have the privilege of the floor at meetings of the Board but shall not have the right to vote.

Section 6. Each Committee shall report monthly to the Board of Managers through its Chairman. A copy of their report shall be in the hands of the Executive Vice President one week before the monthly meeting of the Board.

Section 7. The Bartol Research Foundation Committee shall consist of not less than ten nor more than fifteen members, including the President and the Executive Vice President of the Institute and the Director of the Bartol Research Foundation as *ex officio* members and nine members of the Institute of whom not more than four shall be members of the Board of Managers. The Committee shall, after consultation with the Director of the Bartol Research Foundation and subject to the approval of the Board of Managers, collaborate with the Executive Vice President in carrying out the purposes and determining the policies of the Bartol Research Foundation. It shall appoint the Director and the Staff of the Laboratories, subject to the approval of the Board of Managers. The Director of the Bartol Research Foundation, to whom all other employees of the Foundation shall report, shall have charge of the

scientific activities of the Foundation and shall report on all matters to the Committee or to the Executive Vice President, as the Committee may elect.

Section 8. The Biochemical Research Foundation Committee shall report to the Board of Managers from time to time on the condition of the affairs and operation of said Foundation and shall be available to the Director of the Biochemical Research Foundation and its Advisory Council for collaboration and advice.

Section 9. The Committee on Science and the Arts shall investigate current discoveries, inventions and other achievements in the sciences and their application in the mechanical and industrial arts with a view of affording such recognition as may lie within the power of the Institute to bestow. The Committee shall exercise independent judgment therein. In all matters of a general or administrative nature the Committee shall collaborate with the Executive Vice President.

Section 10. The Endowment Committee shall, in collaboration with the Executive Vice President, encourage the gift of funds to the Institute.

Section 11. The Finance Committee shall have the custody and control of all the securities and investments of the Institute with full power and authority to buy and to sell, and to invest and reinvest the same; including the power to satisfy mortgages and extinguish ground rents, and to direct the placing of all such insurances on Real Estate held for investment as it may deem necessary, and to make such improvements, repairs and alterations to such Real Estate as it may deem necessary. It shall have power to authorize the proper officers of the Institute to execute the necessary papers to effect all purchases, sales and assignments of property other than real estate; to transfer registered securities; to subscribe to bond-holders' agreements to plans of reorganization involving any securities held by the Institute or in which it has an interest; and to do all such acts as are necessary in pursuance of the foregoing powers. It may, with the approval of the Board of Managers, appoint a Trust Company of the City of Philadelphia to act as Fiscal Agent under the direction of the Committee.

The Finance Committee shall keep a record of all its acts and proceedings, which shall be communicated to the Board of Managers.

Section 12. The Library Committee, in collaboration with the Executive Vice President, shall be of counsel and advice in the purchase of books and publications suitable to and consonant with the purposes of the Library; and in other matters pertaining to the Library.

Section 13. The Meetings Committee shall, in collaboration with the Executive Vice President, secure for presentation before the Institute papers dealing authoritatively with subjects of import in the fields of science, engineering and industry.

Section 14. The Membership Committee shall, in collaboration with the Executive Vice President, promote the several memberships defined in ARTICLE II of these By-Laws.

Section 15. The Museum and Memorial Committee shall, in collaboration with the Executive Vice President, be of counsel and advice to the Director of the Benjamin Franklin Memorial and The Franklin Institute Museum, and with the scientific staff of the Museum concerning the activities and the exhibits of both the Museum and the Memorial.

Section 16. The Publications Committee, in collaboration with the Executive Vice President, shall be of counsel and advice with regard to all publications of the Institute other than publications of the Bartol Research Foundation.

Section 17. The Committee on Research shall, in collaboration with the Executive Vice President, be of counsel and advice to all research activities of the Institute except those of the Bartol and Biochemical Foundations.

Section 18. Each committee shall organize and adopt rules as it sees fit, subject to the provisions of these By-Laws and the approval of the Board of Managers.

ARTICLE IX

MEETINGS

Section 1. The Institute shall hold stated meetings on the third Wednesday of each month, except in June, July, August and September, at 8:15 P.M.

Section 2. Special meetings shall be called

by the President upon the order of the Board of Managers or within ten days upon the written application of twenty-four voting members of the Institute.

Section 3. Twenty-four members shall constitute a quorum at any stated or special meeting.

Section 4. The Annual Meeting of the Institute shall be held on the third Wednesday of January of each year at 8:15 P.M. Elections at Annual Meetings shall not result from the poll of less than forty-eight ballots cast in accordance with ARTICLE VI, Section 6, of these By-Laws.

ARTICLE X

AMENDMENTS

These By-Laws may be altered or amended at any stated meeting of the members of the Institute, provided notice in writing, signed by two members, of the proposed alteration or amendment, shall be given to the Board of Managers two months prior to the said meeting, except that amendments to ARTICLE I: relating to capital stock, must be ratified subsequently by a majority of the stock represented at a meeting specially called for this purpose.